US010553671B2

(12) **United States Patent**
Zuo et al.

(10) **Patent No.: US 10,553,671 B2**
(45) **Date of Patent: Feb. 4, 2020**

(54) **3D PILLAR INDUCTOR**

(71) Applicant: **QUALCOMM Incorporated**, San Diego, CA (US)

(72) Inventors: **Chengjie Zuo**, Santee, CA (US); **Jonghae Kim**, San Diego, CA (US); **Daeik Daniel Kim**, Del Mar, CA (US); **Changhan Hobie Yun**, San Diego, CA (US); **Mario Francisco Velez**, San Diego, CA (US)

(73) Assignee: **QUALCOMM Incorporated**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 450 days.

(21) Appl. No.: **15/178,900**

(22) Filed: **Jun. 10, 2016**

(65) **Prior Publication Data**

US 2016/0284789 A1 Sep. 29, 2016

Related U.S. Application Data

(62) Division of application No. 14/229,317, filed on Mar. 28, 2014, now Pat. No. 9,368,564.

(51) **Int. Cl.**

H01L 29/00	(2006.01)
H01L 49/02	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC .... ***H01L 28/10*** (2013.01); ***H01F 17/0013*** (2013.01); ***H01F 27/2804*** (2013.01); (Continued)

(58) **Field of Classification Search**

CPC H01L 2924/00014; H01L 2924/00; H01L 2924/181; H01L 2924/014; H01L 2924/00012; H01L 2924/12042; H01L 2924/1305; H01L 2924/15311; H01L 2924/13091; H01L 2924/01047; H01L 2924/0105; H01L 2924/01; H01L 21/486; H01L 21/4889; H01L 21/76885; H01L 21/02274; H01L 21/3065; H01L 21/31116;

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,461,353	A	10/1995	Eberhardt
6,531,945	B1	3/2003	Ahn et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1635637	A	7/2005
JP	H0284303	U	6/1990

(Continued)

OTHER PUBLICATIONS

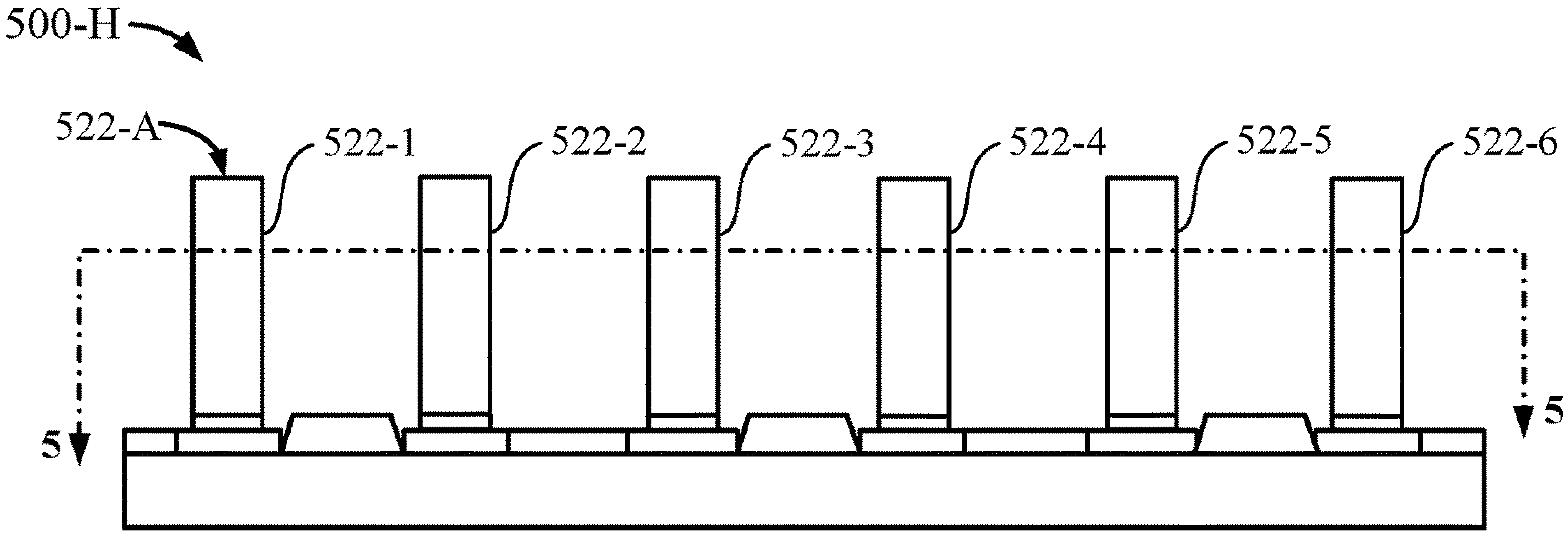
International Search Report and Written Opinion—PCT/US2015/021655—ISA/EPO—dated Aug. 7, 2015.

Primary Examiner — Shouxiang Hu
Assistant Examiner — Rodolfo D. Fortich
(74) *Attorney, Agent, or Firm* — Muncy, Geissler, Olds & Lowe

(57) **ABSTRACT**

Base pads are spaced by a pitch on a support surface. Conducting members, optionally Cu or other metal pillars, extend up from the base pads to top pads. A top pad interconnector connects the top pads in a configuration establishing an inductor current path between the base pads.

9 Claims, 11 Drawing Sheets



(51) **Int. Cl.**

H01L 21/48	(2006.01)
H01F 17/00	(2006.01)
H01L 23/522	(2006.01)
H01L 23/498	(2006.01)
H01L 23/48	(2006.01)
H01L 23/64	(2006.01)
H01F 27/28	(2006.01)
H01L 23/00	(2006.01)

(52) **U.S. Cl.**

CPC ***H01L 21/486*** (2013.01); ***H01L 21/4889*** (2013.01); ***H01L 23/481*** (2013.01); ***H01L 23/49822*** (2013.01); ***H01L 23/49827*** (2013.01); ***H01L 23/49838*** (2013.01); ***H01L 23/49866*** (2013.01); ***H01L 23/5227*** (2013.01); ***H01L 23/642*** (2013.01); ***H01L 24/17*** (2013.01); *H01F 2017/002* (2013.01); *H01F 2017/0073* (2013.01); *H01L 2224/13014* (2013.01); *H01L 2224/13016* (2013.01); *H01L 2224/16227* (2013.01); *H01L 2224/16265* (2013.01); *H01L 2924/01029* (2013.01); *H01L 2924/14* (2013.01); *H01L 2924/19011* (2013.01); *H01L 2924/19042* (2013.01); *H01L 2924/19102* (2013.01)

(58) **Field of Classification Search**

CPC H01L 21/31138; H01L 21/32136; H01L 21/4853; H01L 21/56; H01L 21/568; H01L 21/6835; H01L 21/76879; H01L 28/10; H01L 23/5227; H01L 23/645; H01L 23/49822; H01L 23/481; H01L 23/49827; H01L 23/49838; H01L 23/49866; H01L 24/17; H01L 2224/13014; H01L 2224/13016; H01L 2224/16227; H01L 2224/16265; H01L 2924/01029; H01L 2924/14; H01L 2924/19011; H01L 2924/19042; H01L 2924/19102

USPC 257/758, 531, 778, 774, 777

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,518,248	B2	4/2009	Li et al.	
7,786,836	B2 *	8/2010	Gabara	H01F 17/0006 336/200
8,143,952	B2	3/2012	Kim et al.	
8,384,507	B2	2/2013	Li et al.	
10,170,836	B2 *	1/2019	Yosui	H01Q 7/08
2004/0124961	A1	7/2004	Aoyagi	
2005/0093659	A1 *	5/2005	Larson, III	H03H 9/132 333/191
2005/0179514	A1 *	8/2005	Yamamoto	H01F 17/0013 336/200
2006/0049905	A1 *	3/2006	Maeda	H01F 17/0013 336/200
2006/0081397	A1 *	4/2006	Enchi	H05K 1/165 174/260
2006/0145805	A1	7/2006	Kim et al.	
2007/0085648	A1	4/2007	Lee et al.	
2010/0090319	A1 *	4/2010	Hsu	H01L 23/481 257/621
2010/0225434	A1 *	9/2010	Wang	H01F 17/0013 336/200
2011/0101497	A1	5/2011	Bizen et al.	
2011/0140825	A1	6/2011	Kim et al.	
2011/0234357	A1	9/2011	Kim et al.	
2011/0291232	A1	12/2011	Yen et al.	
2012/0056680	A1 *	3/2012	Kim	H01F 17/0013 330/307
2013/0293336	A1	11/2013	Lo et al.	
2015/0279920	A1	10/2015	Zuo et al.	

FOREIGN PATENT DOCUMENTS

JP	2005259969	A	9/2005
JP	2007165747	A	6/2007
KR	20060078116	A	7/2006
KR	20110067929	A	6/2011
WO	2011044392		4/2011

* cited by examiner

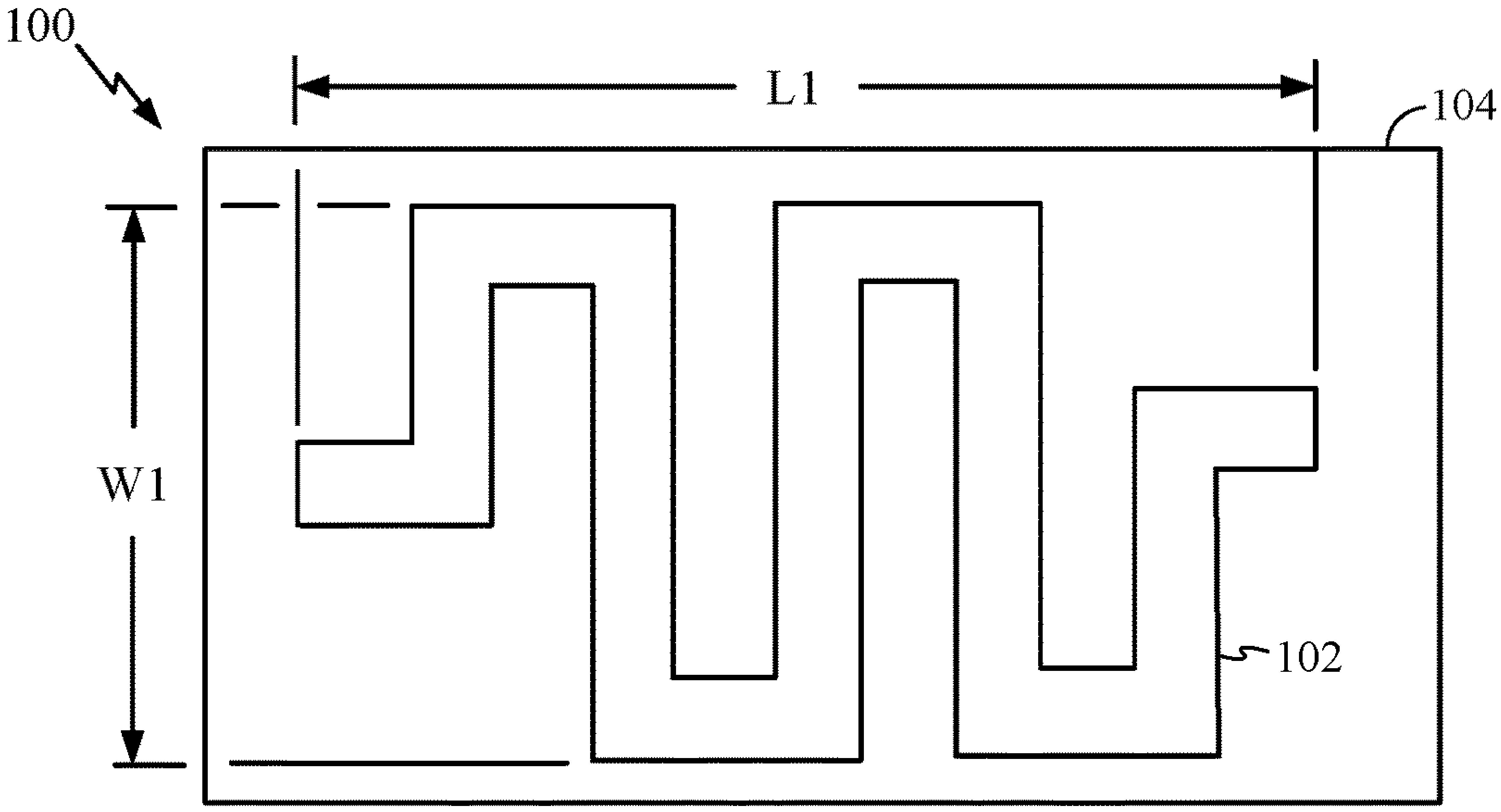


FIG. 1 (Related Art)

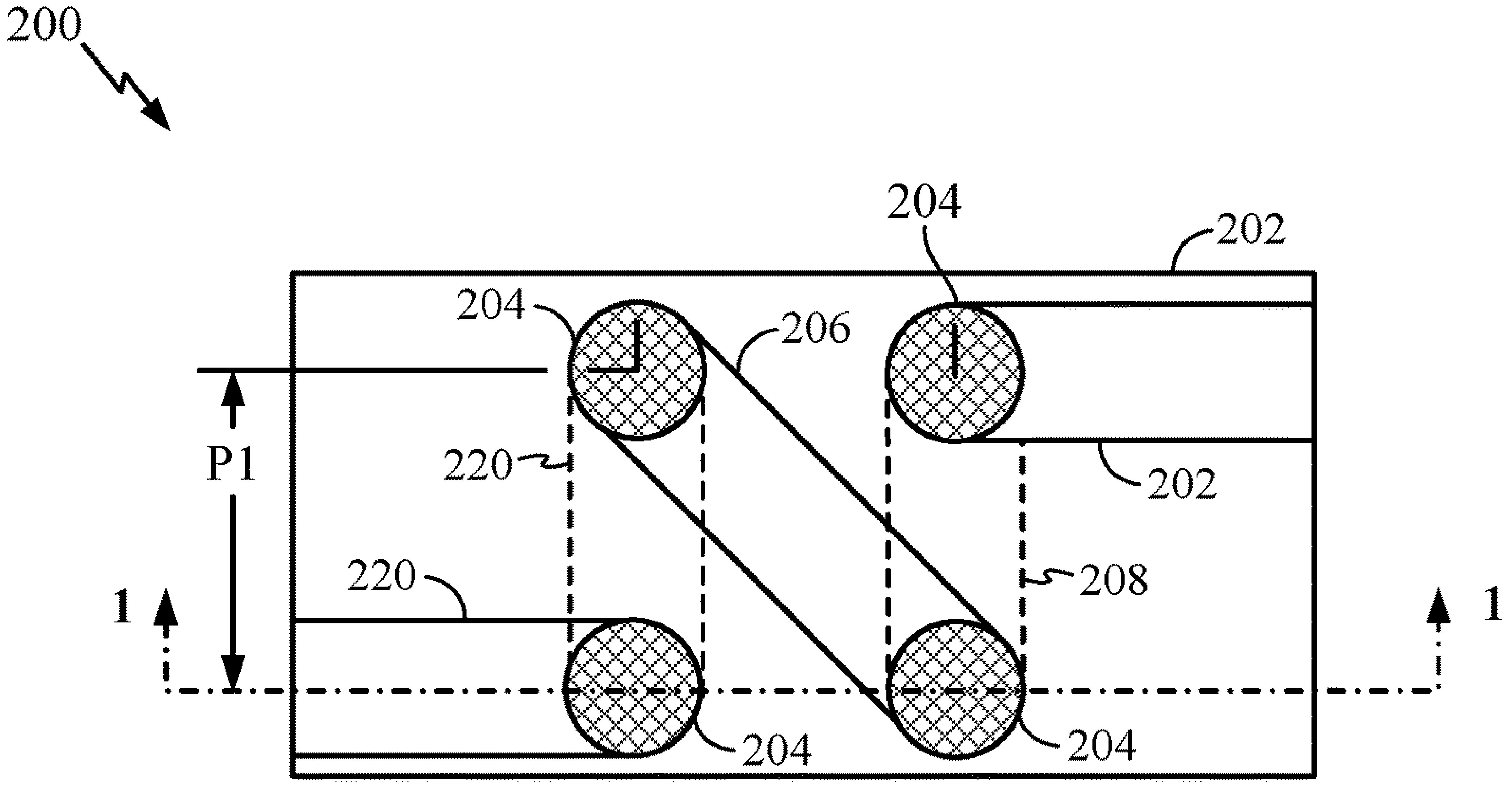


FIG. 2A (Related Art)

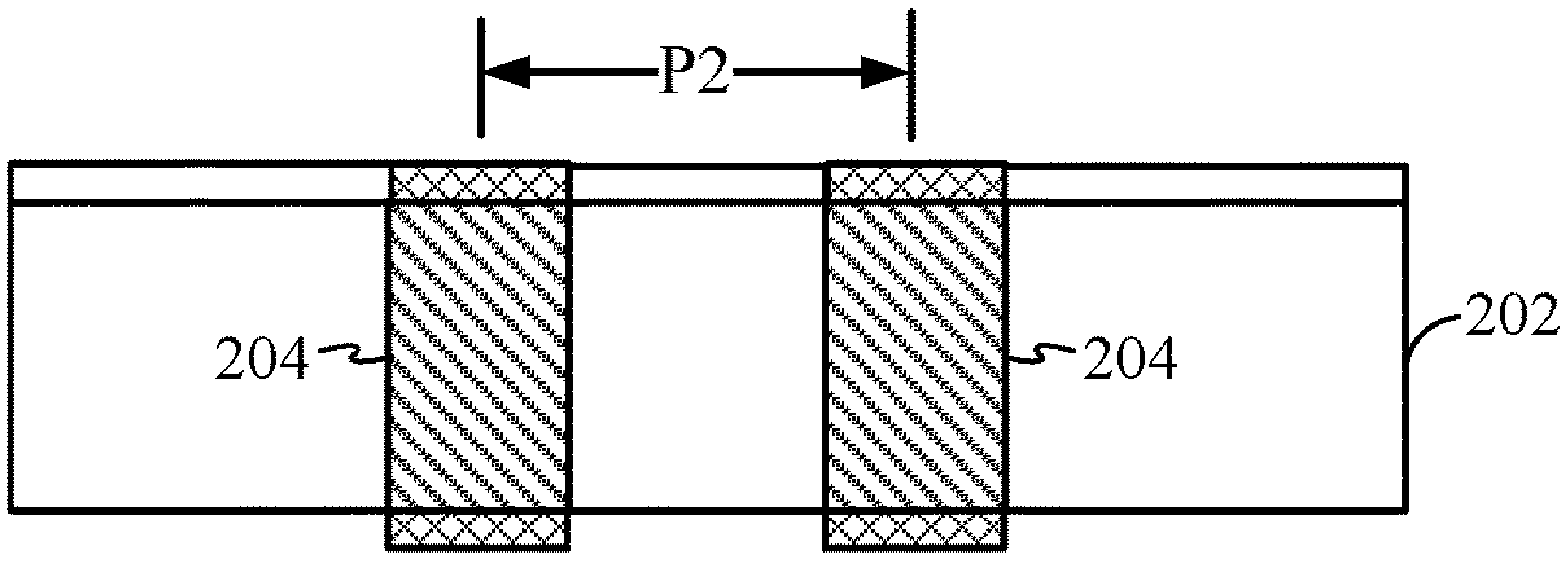


FIG. 2B (Related Art)

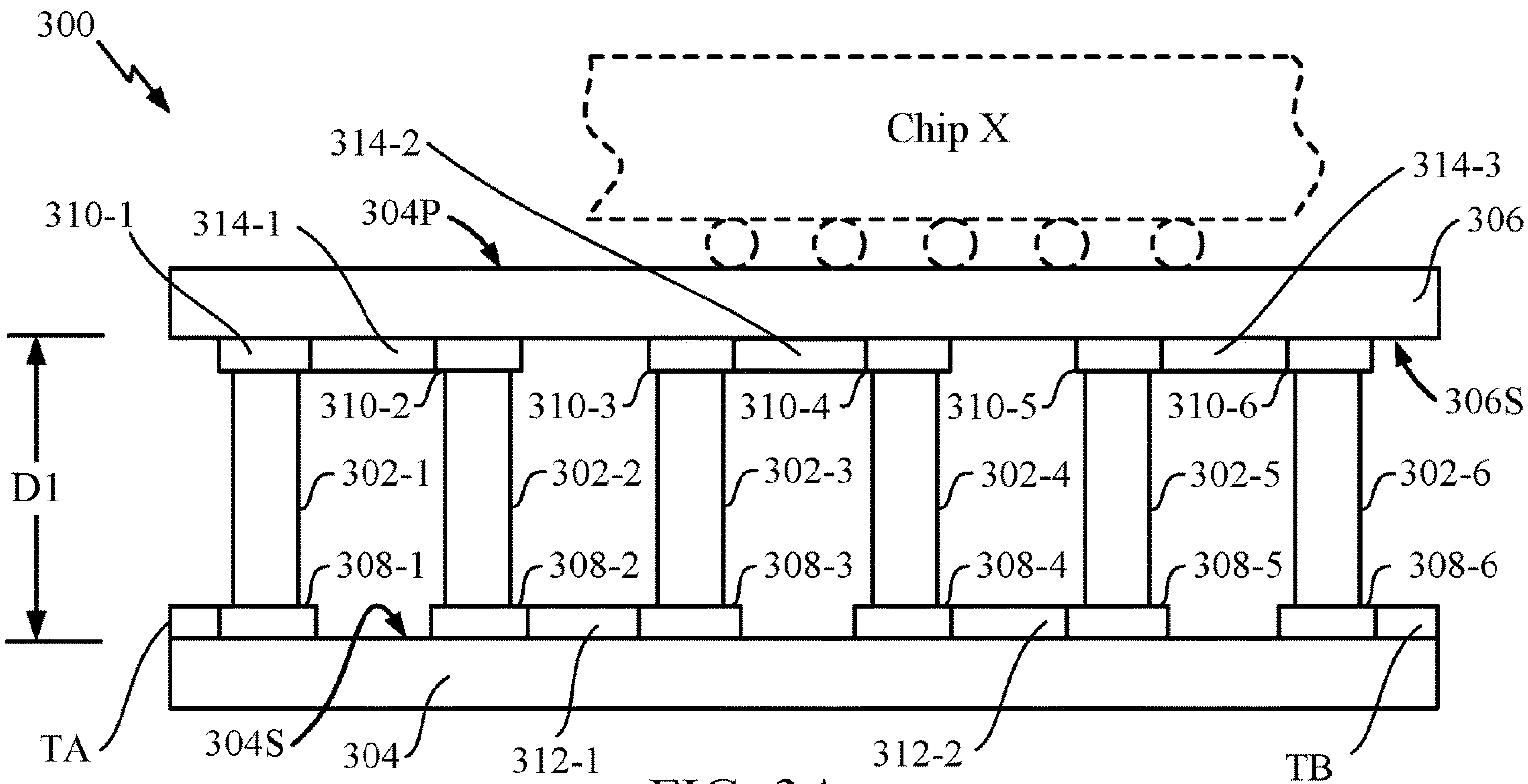


FIG. 3A

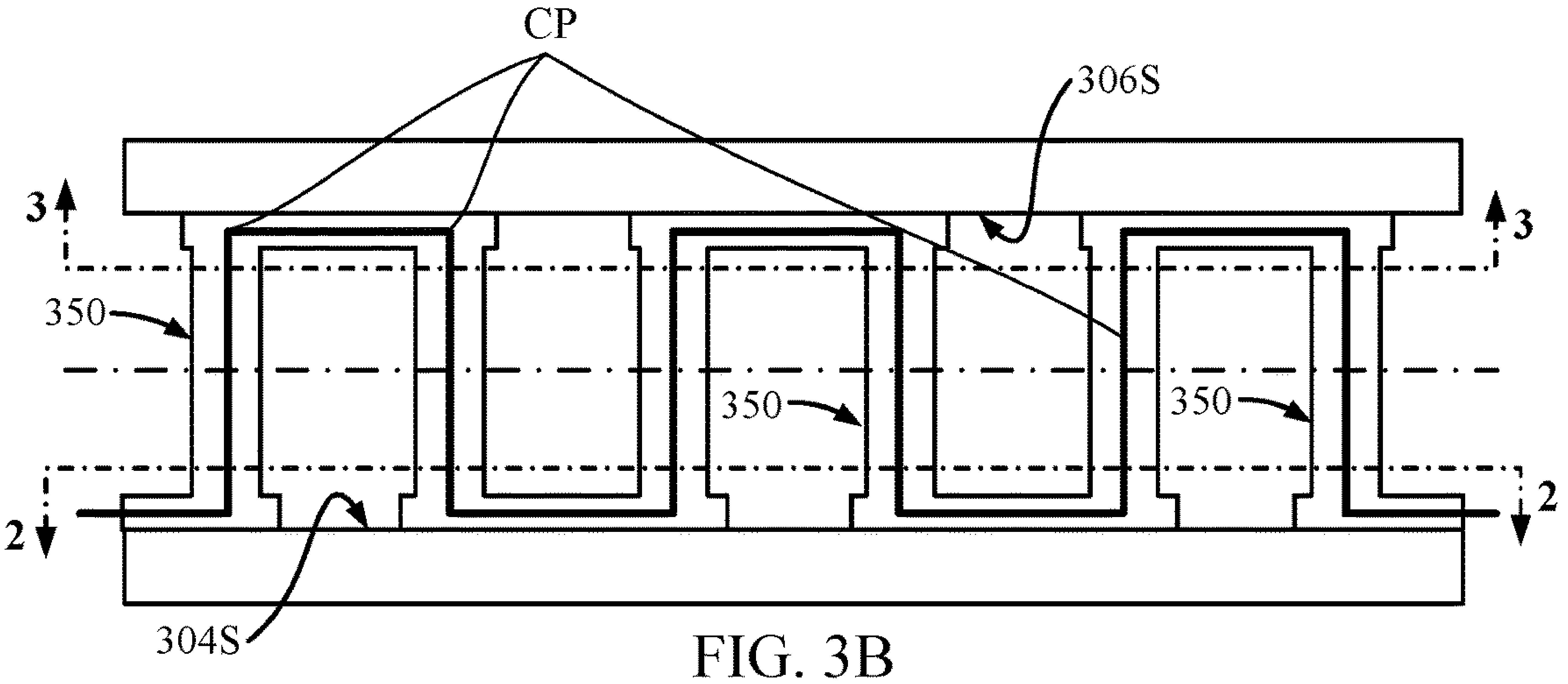


FIG. 3B

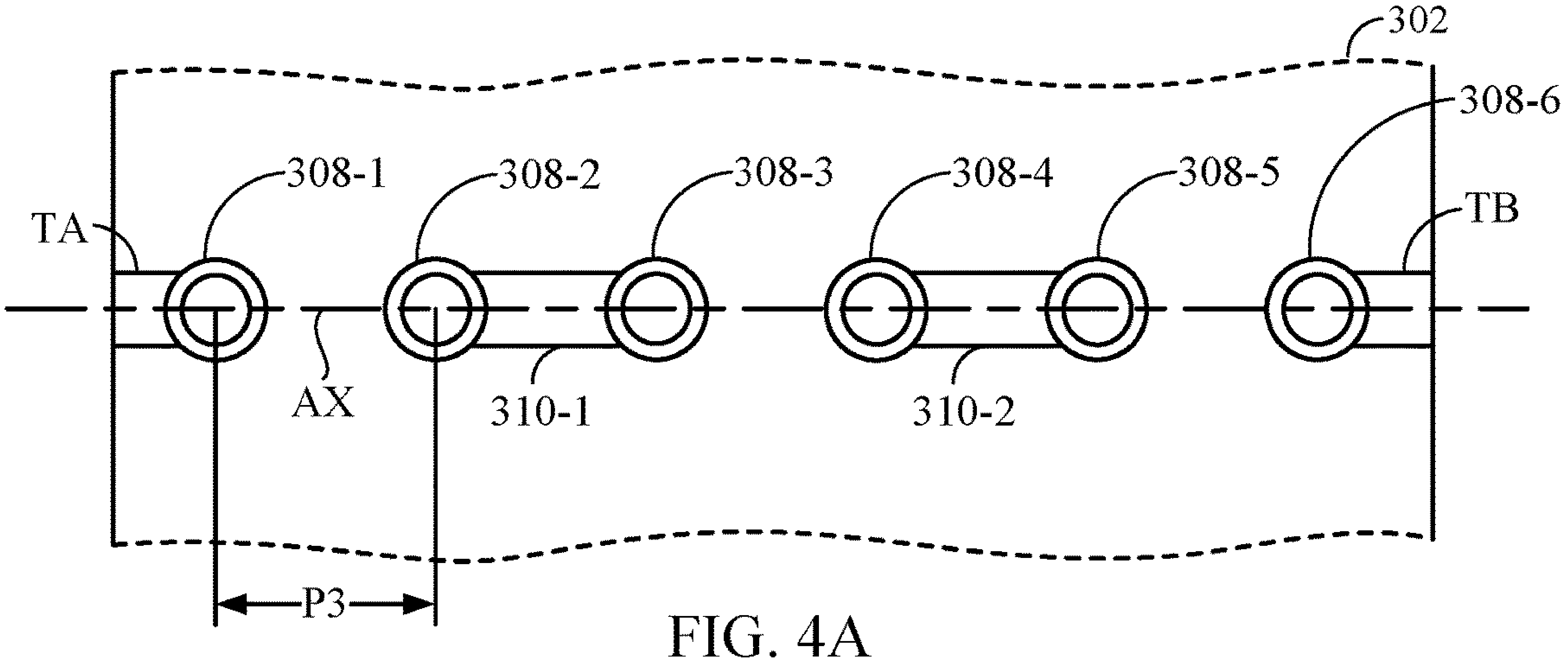


FIG. 4A

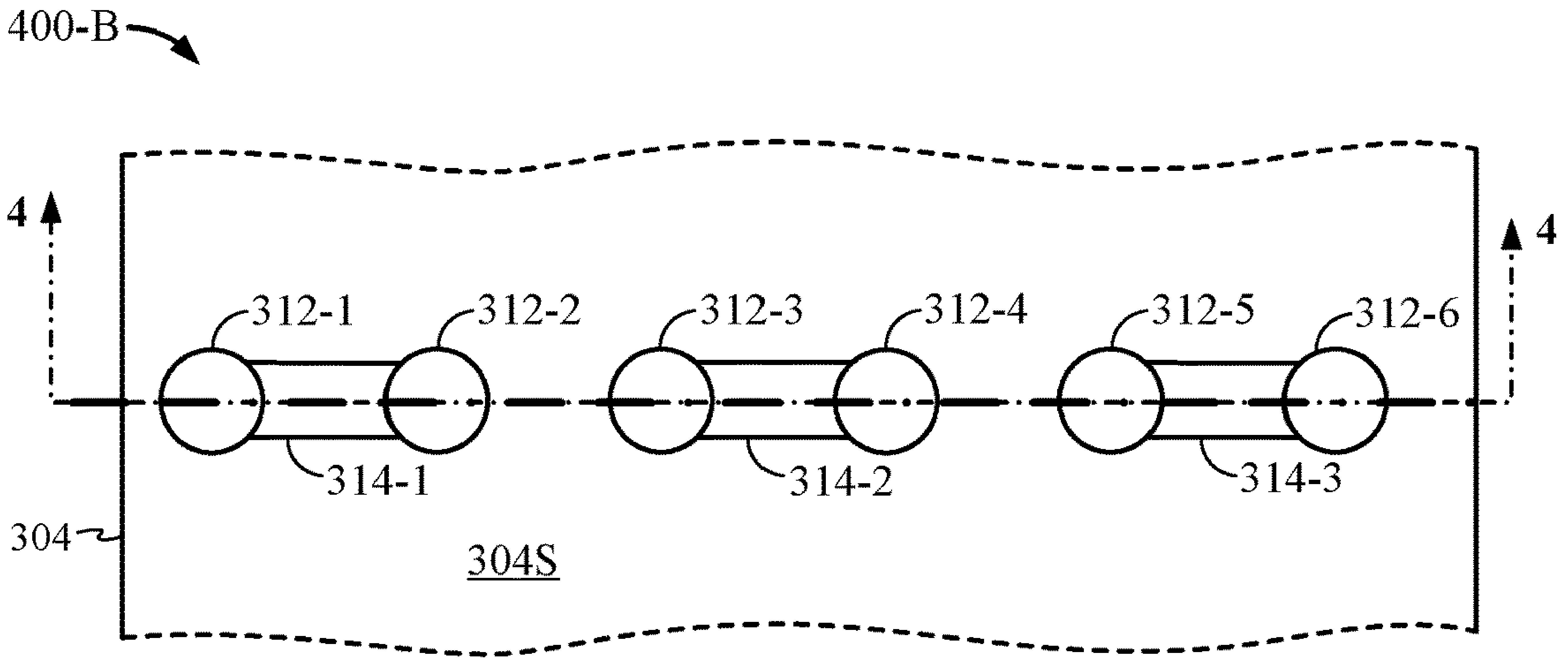


FIG. 4B

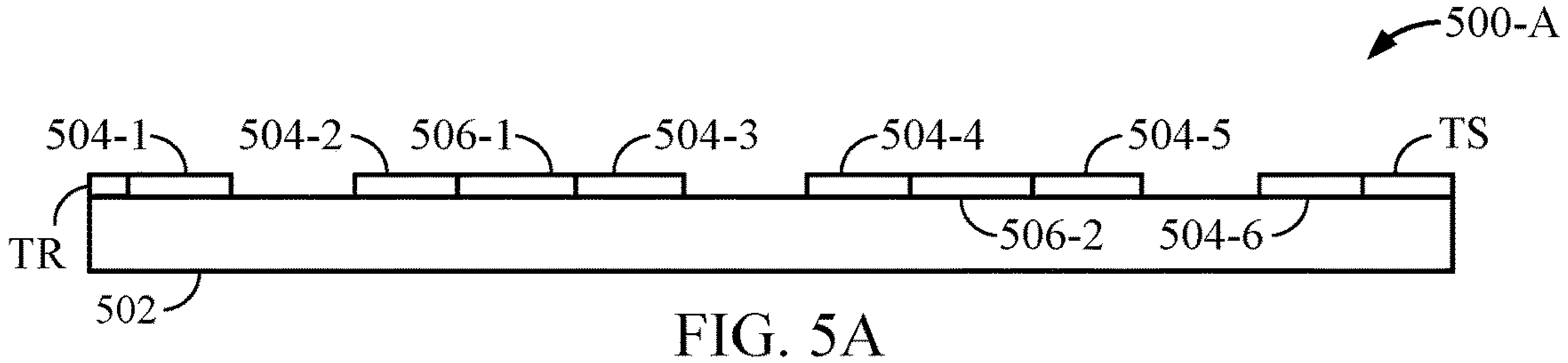


FIG. 5A

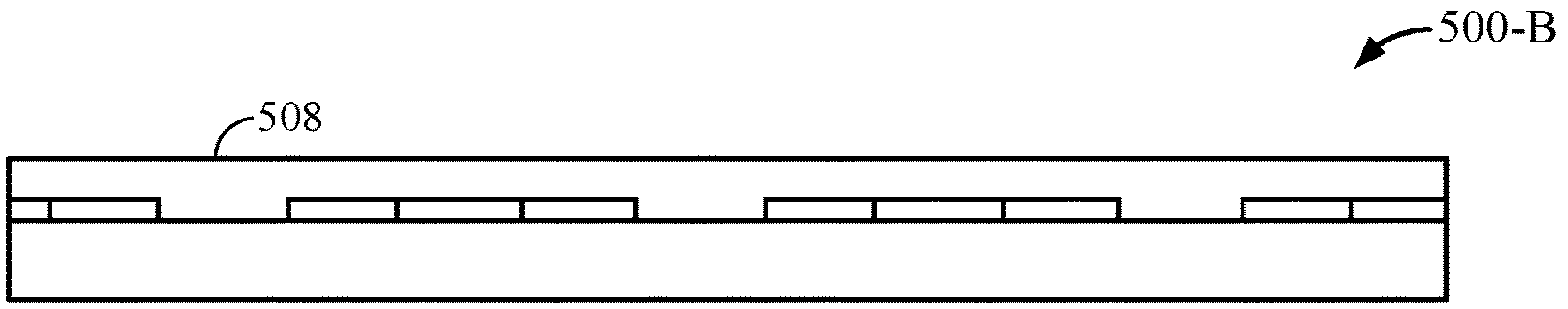


FIG. 5B

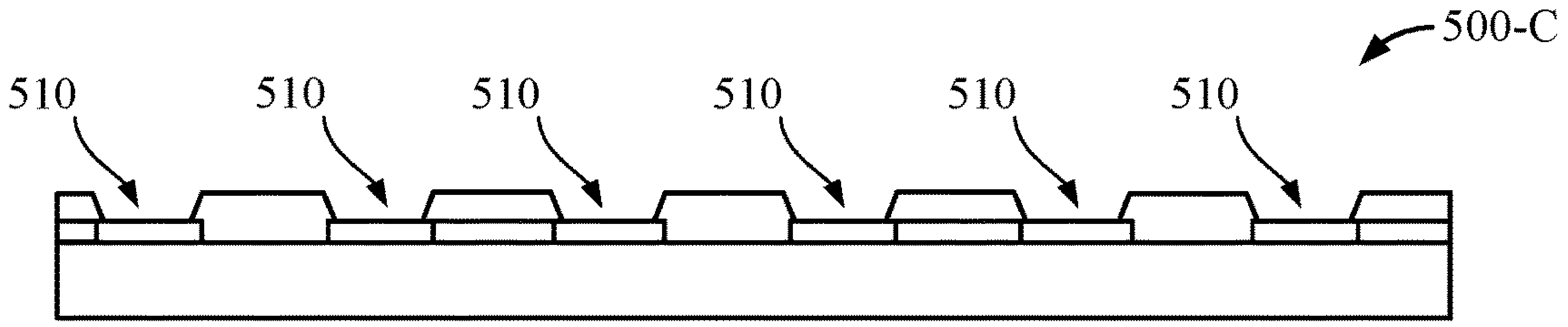


FIG. 5C

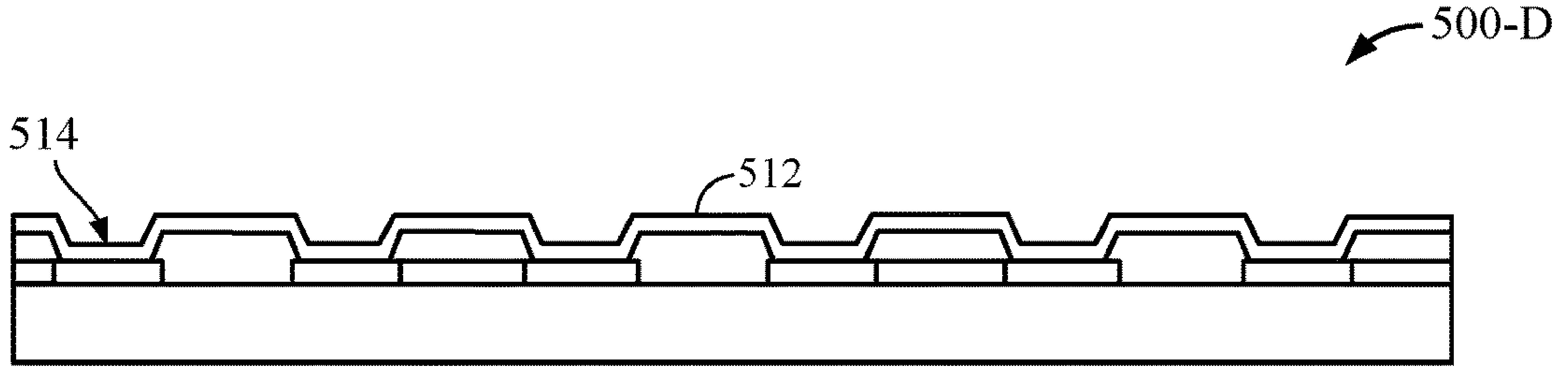


FIG. 5D

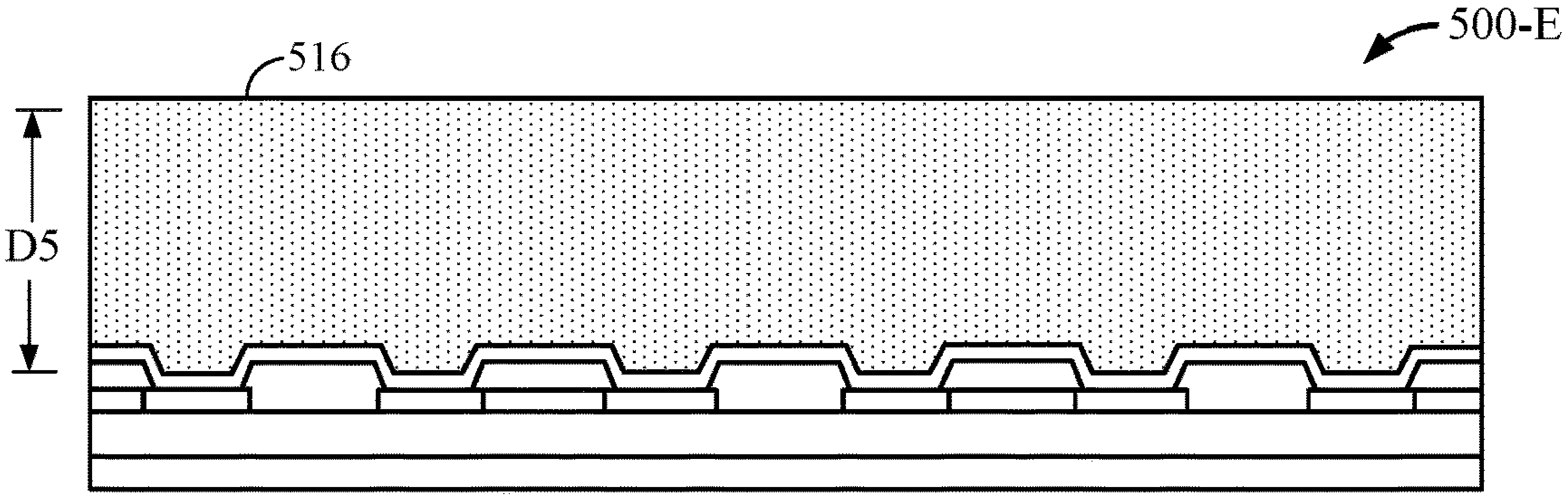


FIG. 5E

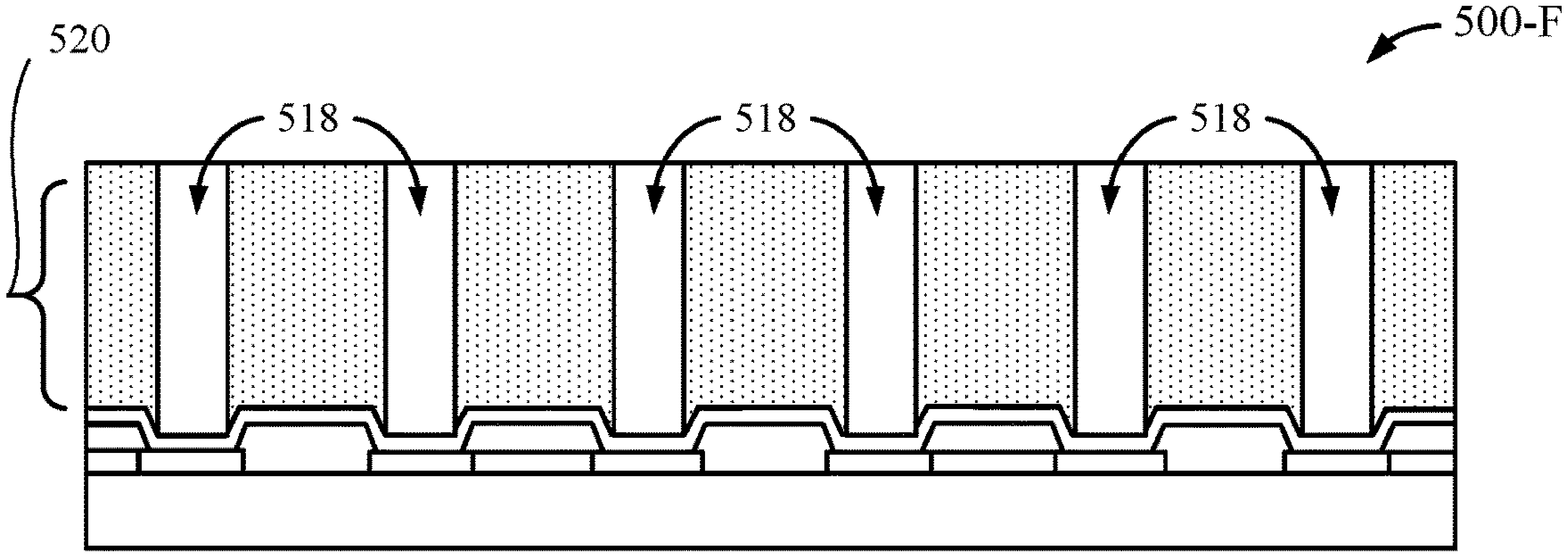


FIG. 5F

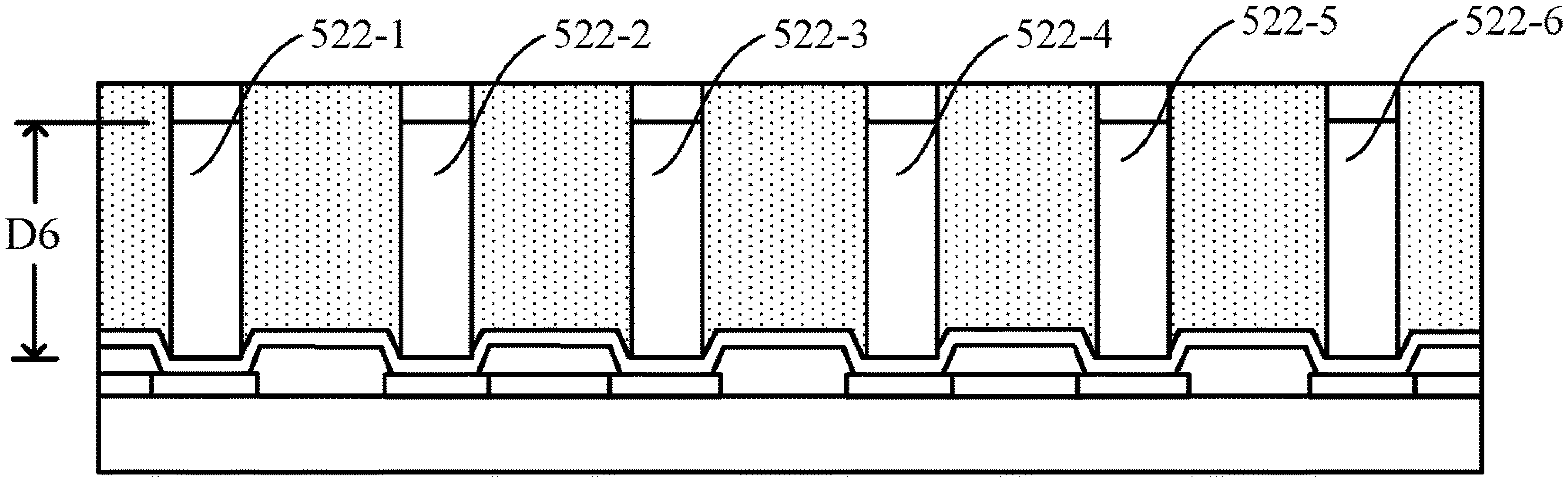


FIG. 5G

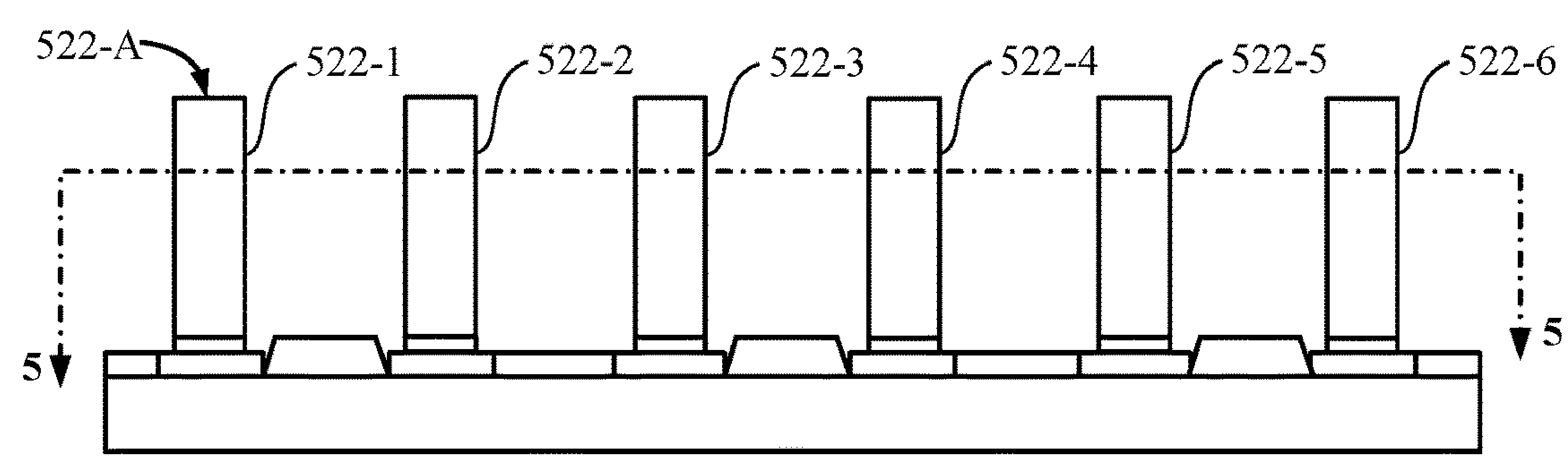


FIG. 5H

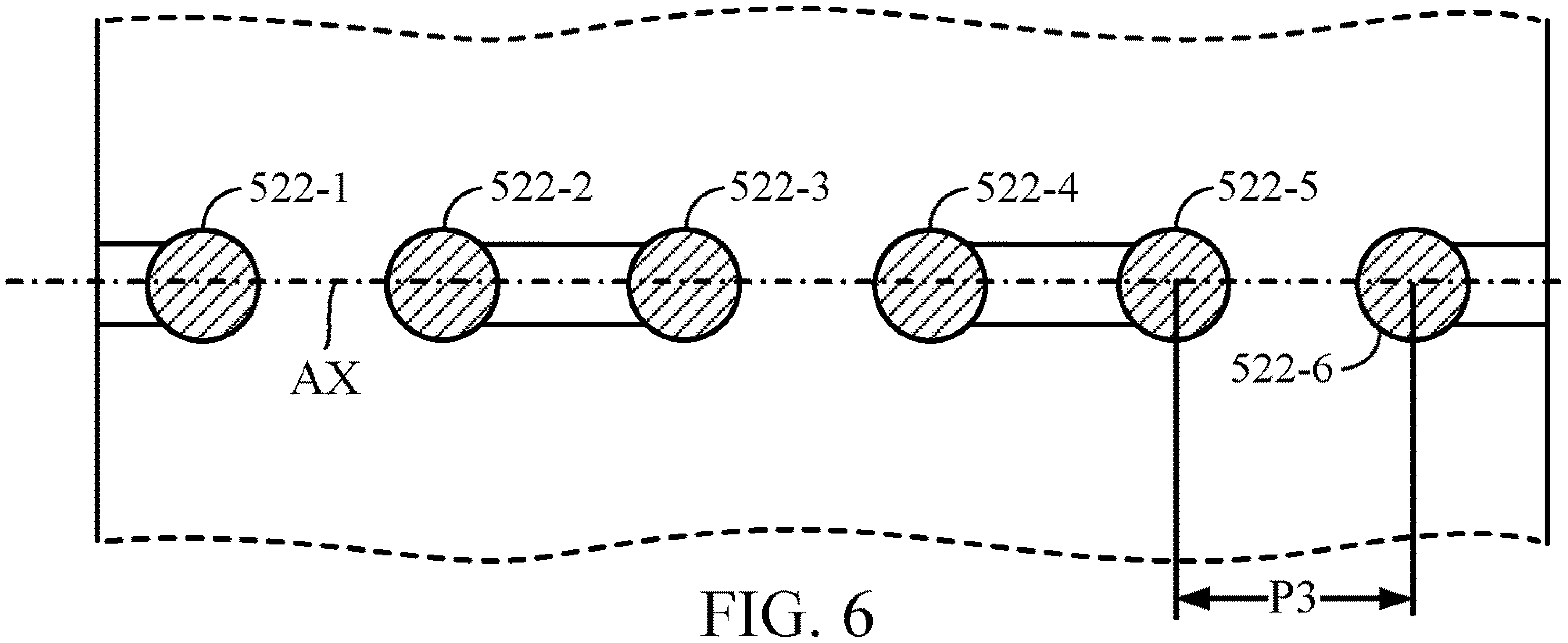


FIG. 6

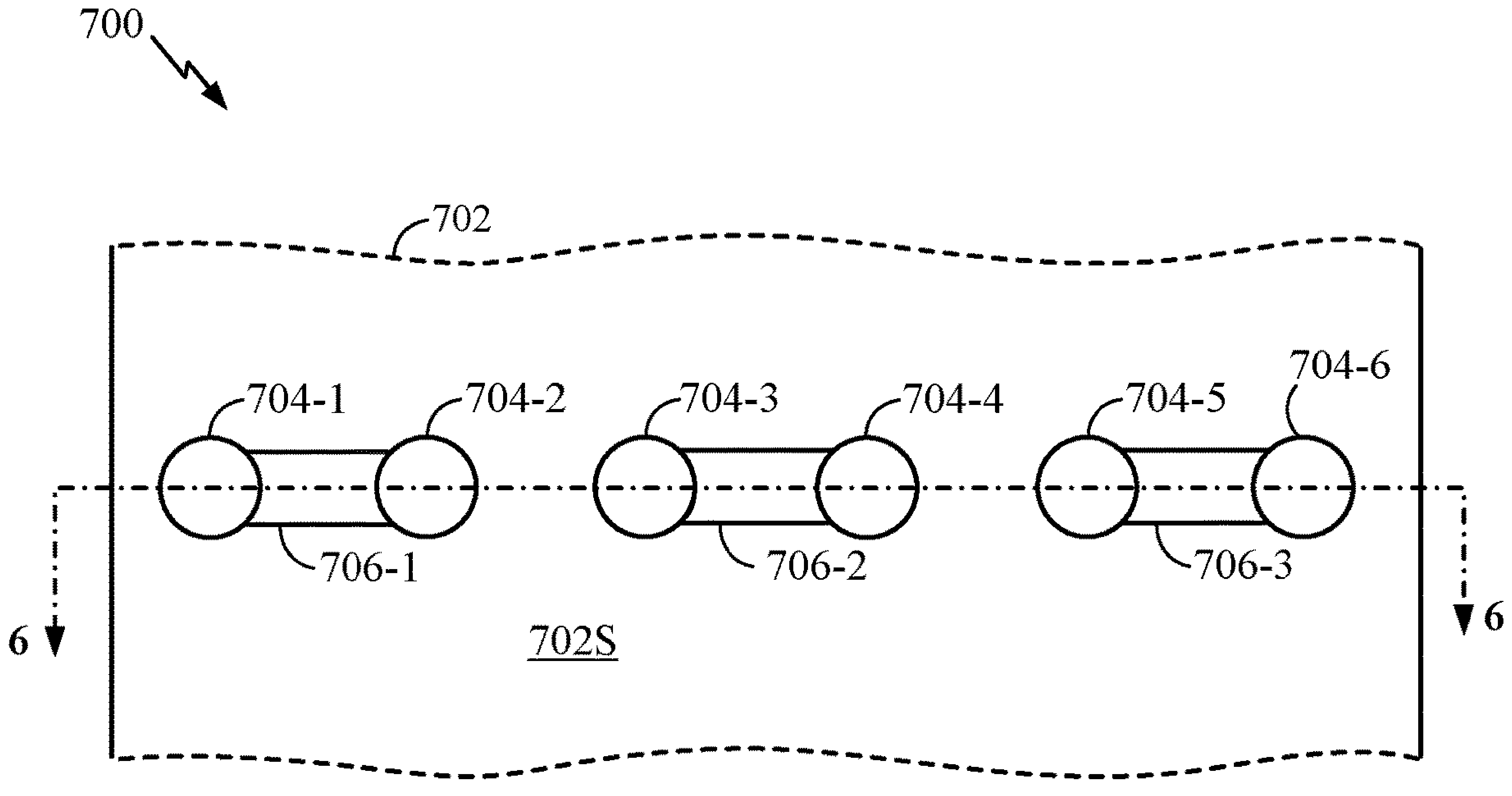


FIG. 7A

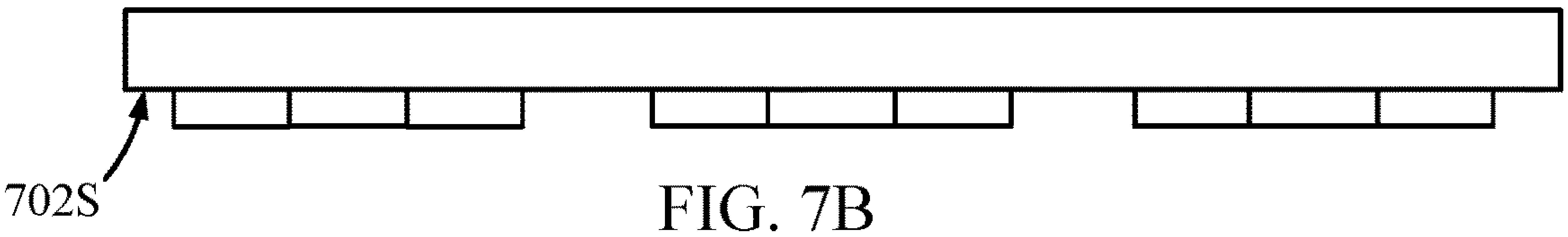


FIG. 7B

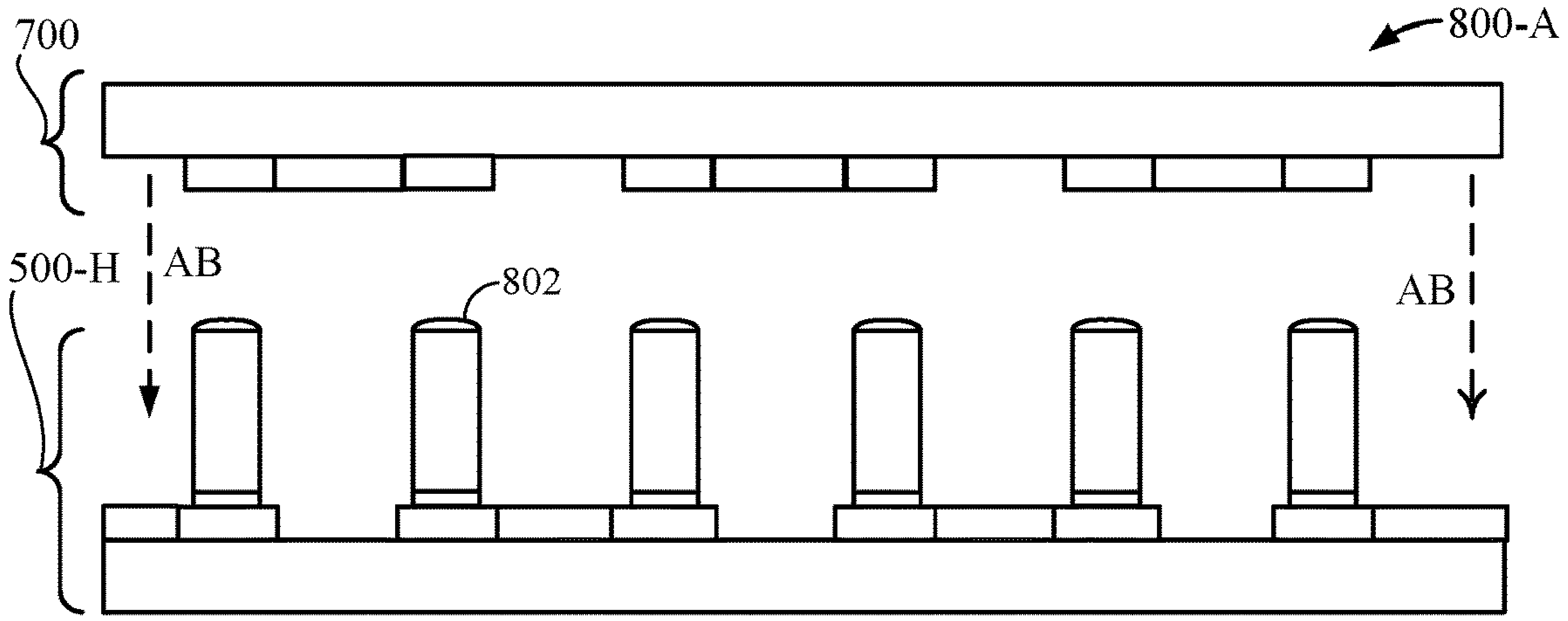


FIG. 8A

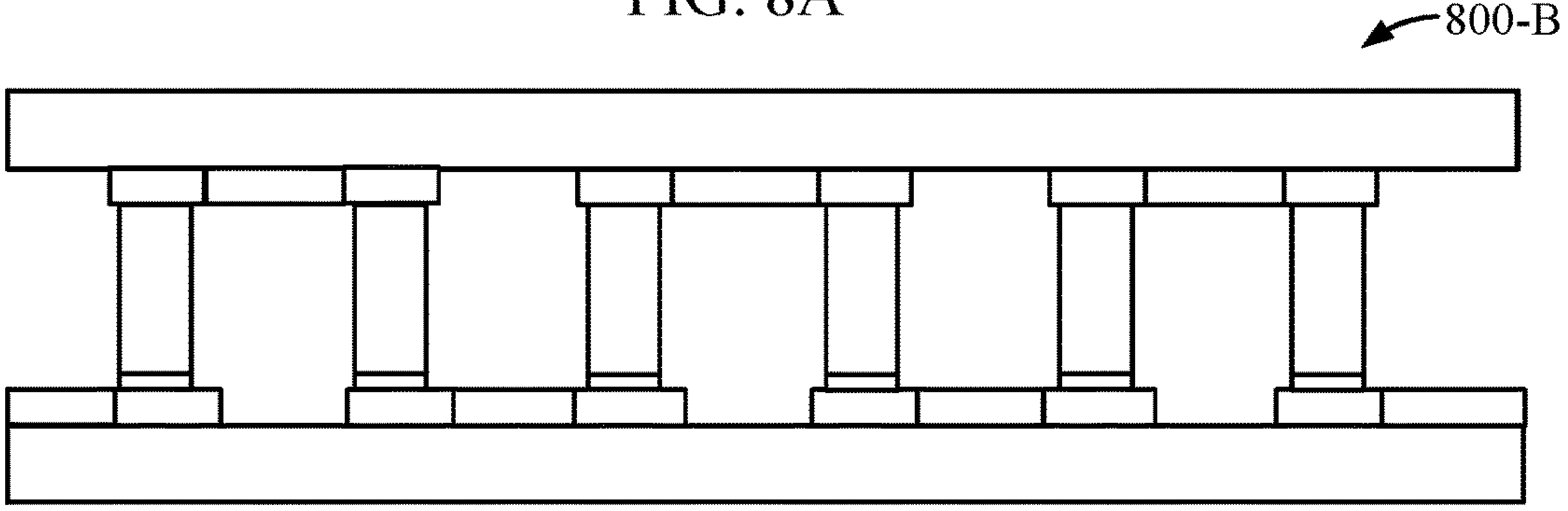


FIG. 8B

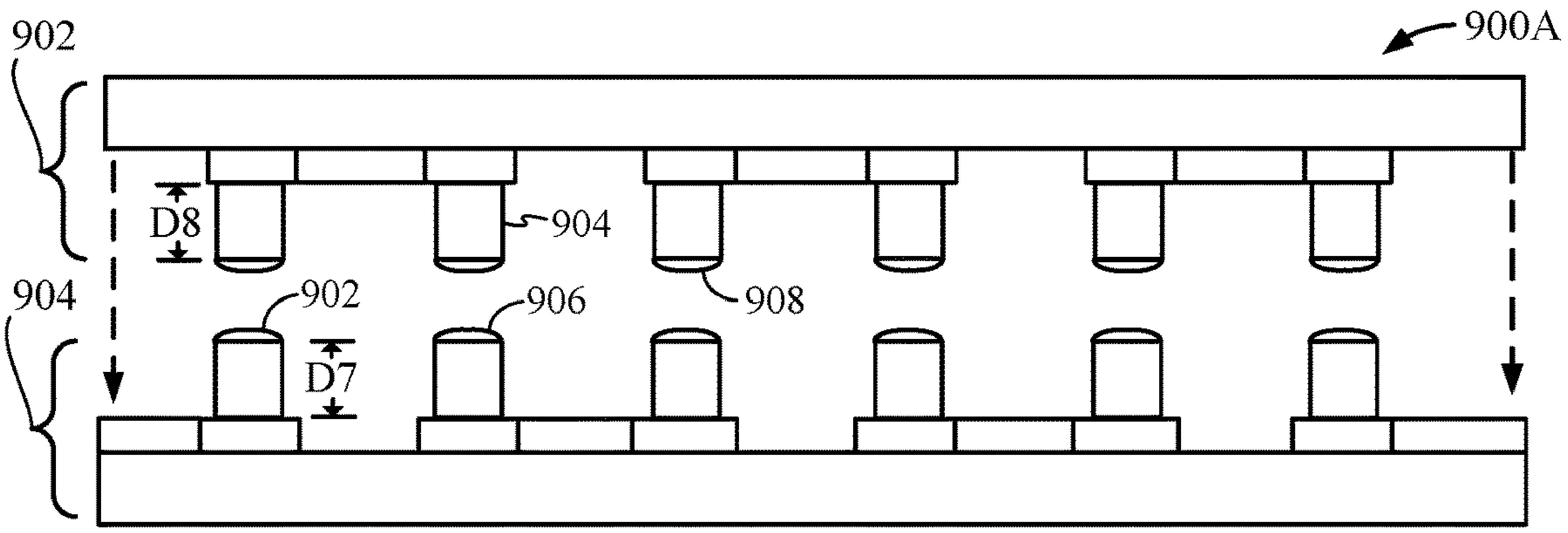


FIG. 9A

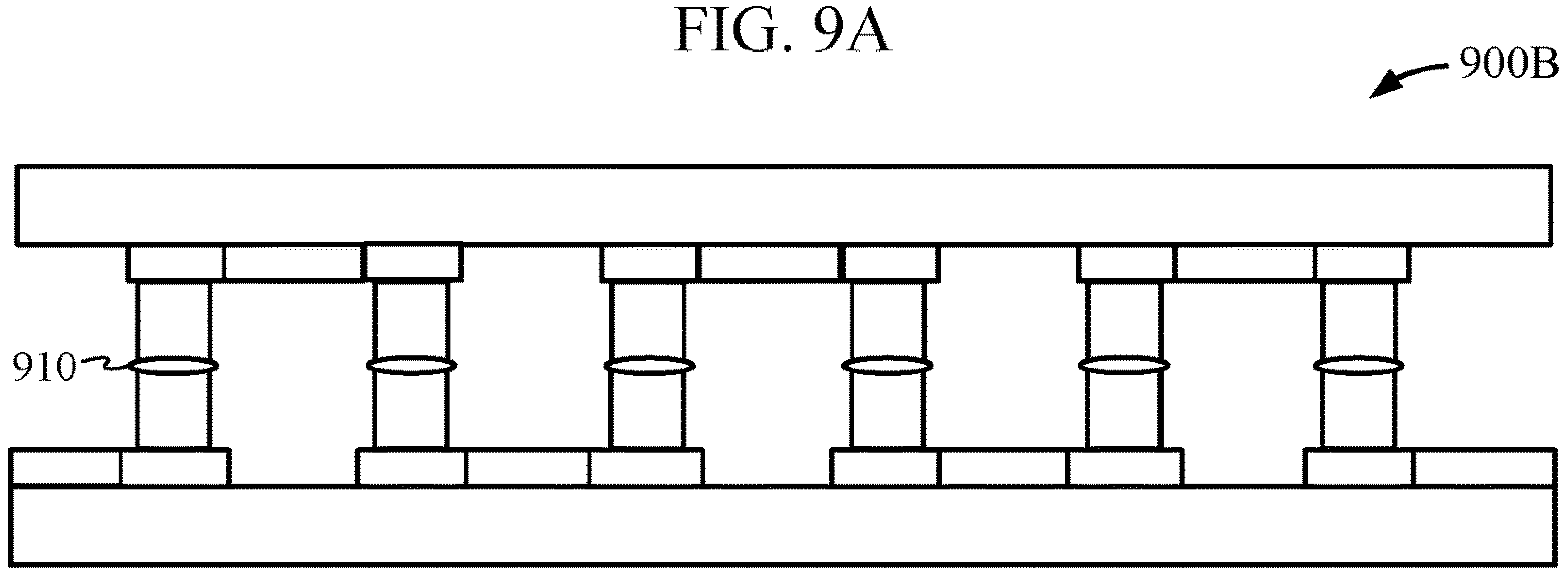


FIG. 9B

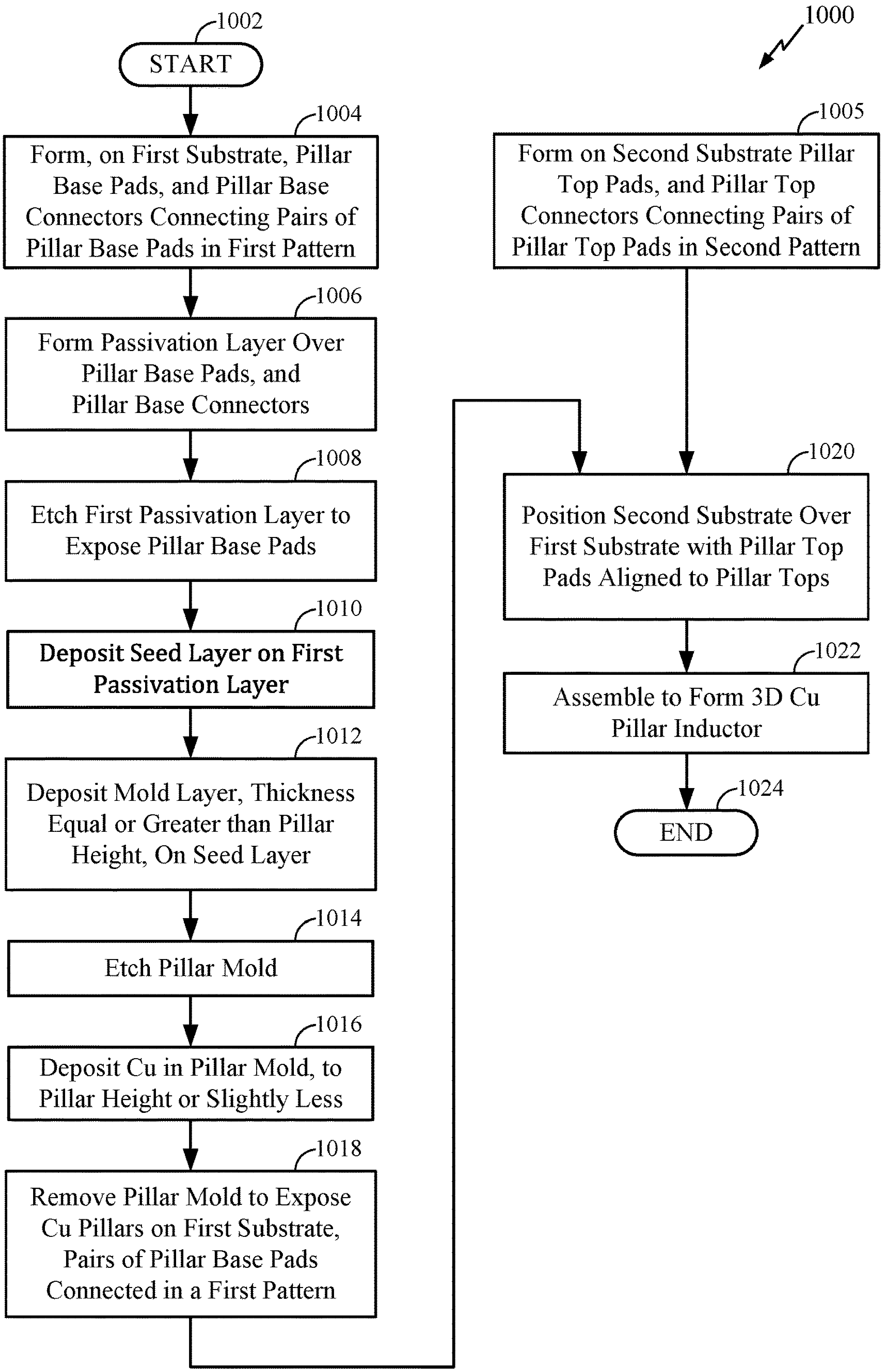

1000
1002
START
1004
Form, on First Substrate, Pillar Base Pads, and Pillar Base Connectors Connecting Pairs of Pillar Base Pads in First Pattern
1006
Form Passivation Layer Over Pillar Base Pads, and Pillar Base Connectors
1008
Etch First Passivation Layer to Expose Pillar Base Pads
1010
Deposit Seed Layer on First Passivation Layer
1012
Deposit Mold Layer, Thickness Equal or Greater than Pillar Height, On Seed Layer
1014
Etch Pillar Mold
1016
Deposit Cu in Pillar Mold, to Pillar Height or Slightly Less
1018
Remove Pillar Mold to Expose Cu Pillars on First Substrate, Pairs of Pillar Base Pads Connected in a First Pattern
1005
Form on Second Substrate Pillar Top Pads, and Pillar Top Connectors Connecting Pairs of Pillar Top Pads in Second Pattern
1020
Position Second Substrate Over First Substrate with Pillar Top Pads Aligned to Pillar Tops
1022
Assemble to Form 3D Cu Pillar Inductor
1024
END

FIG. 10

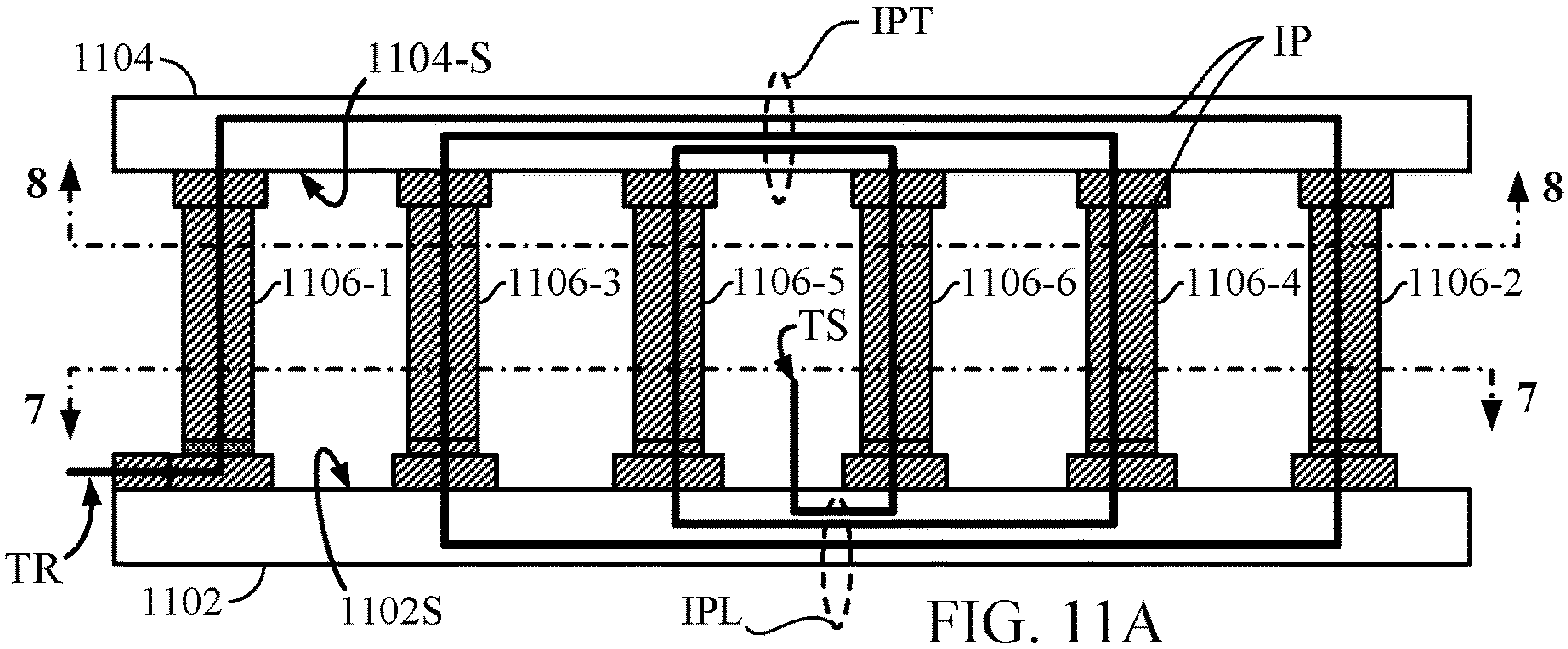


FIG. 11A

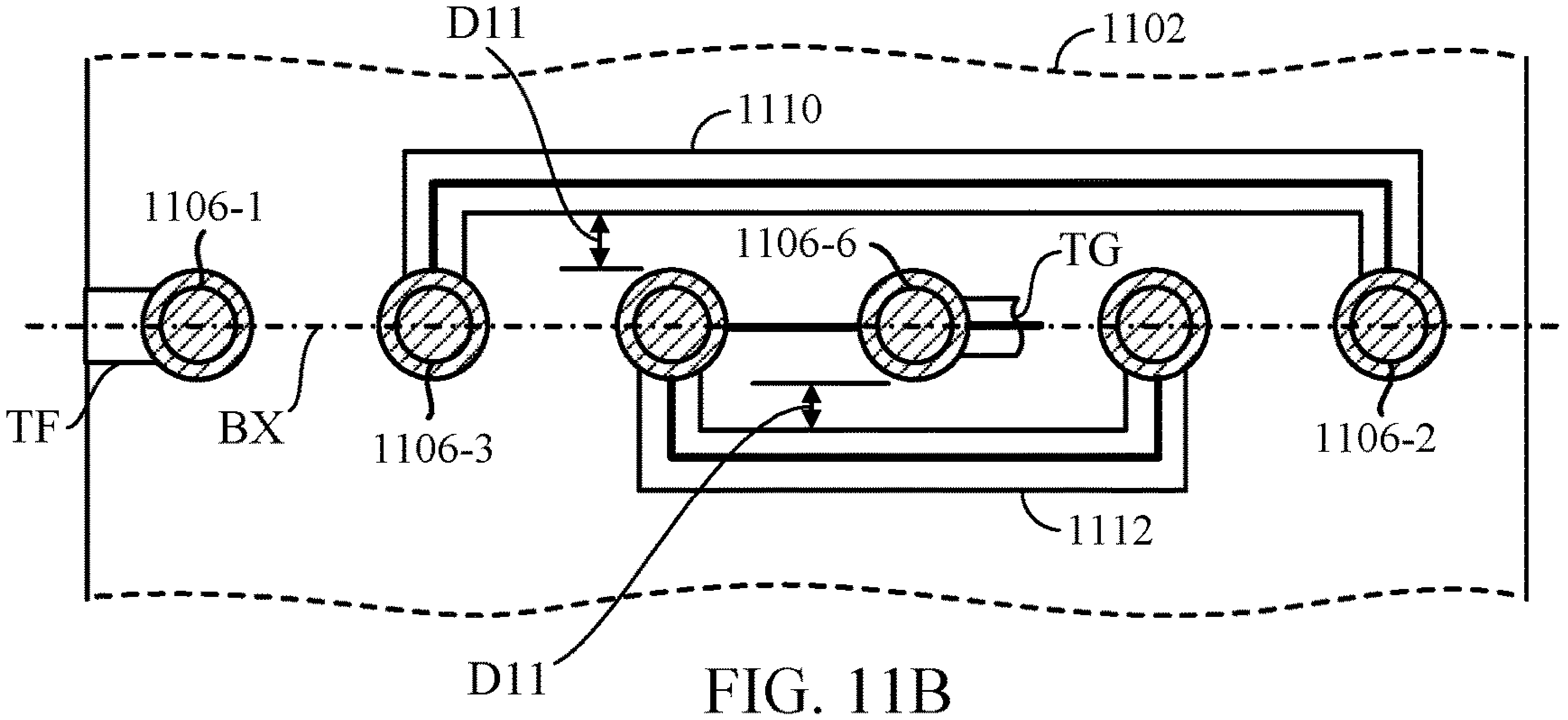


FIG. 11B

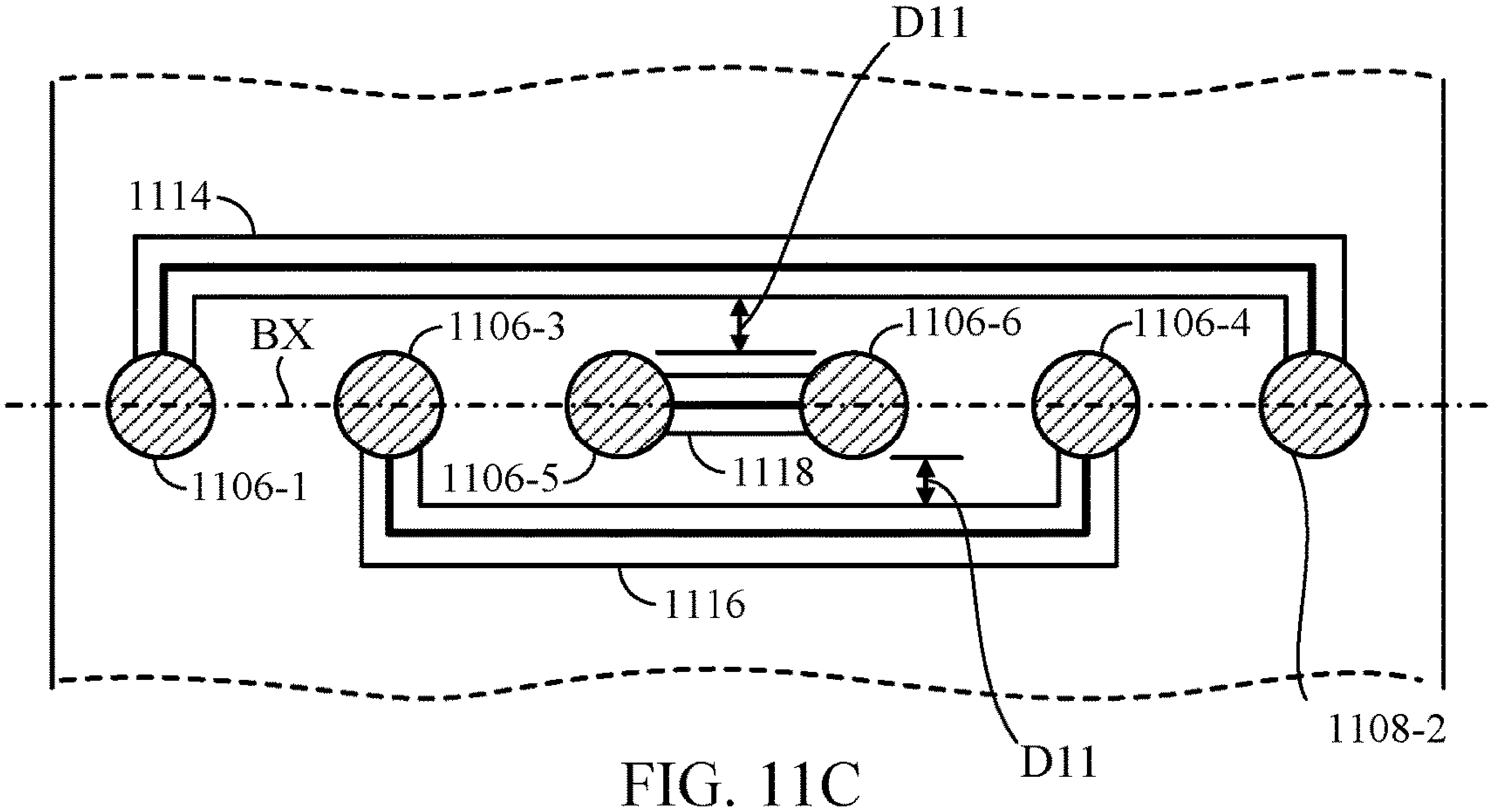


FIG. 11C

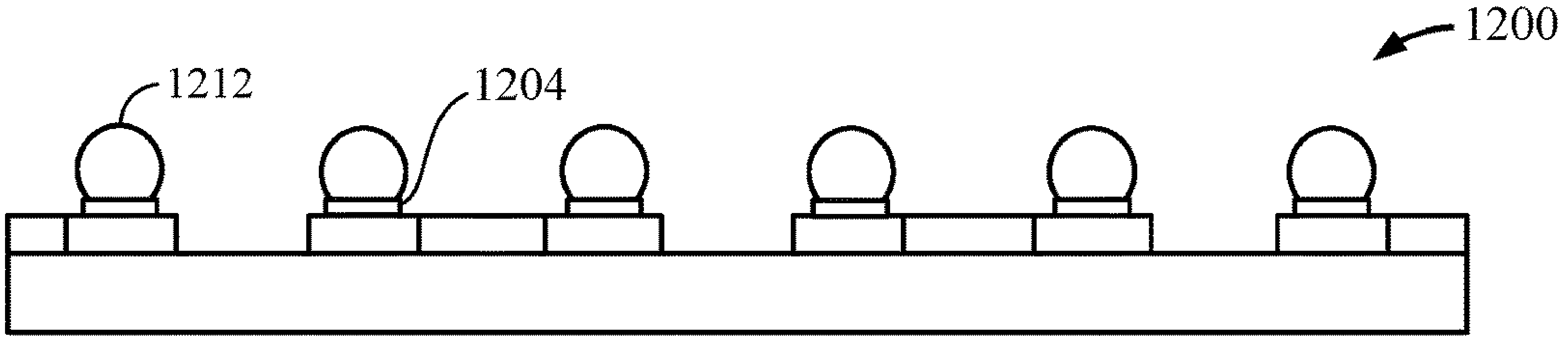


FIG. 12

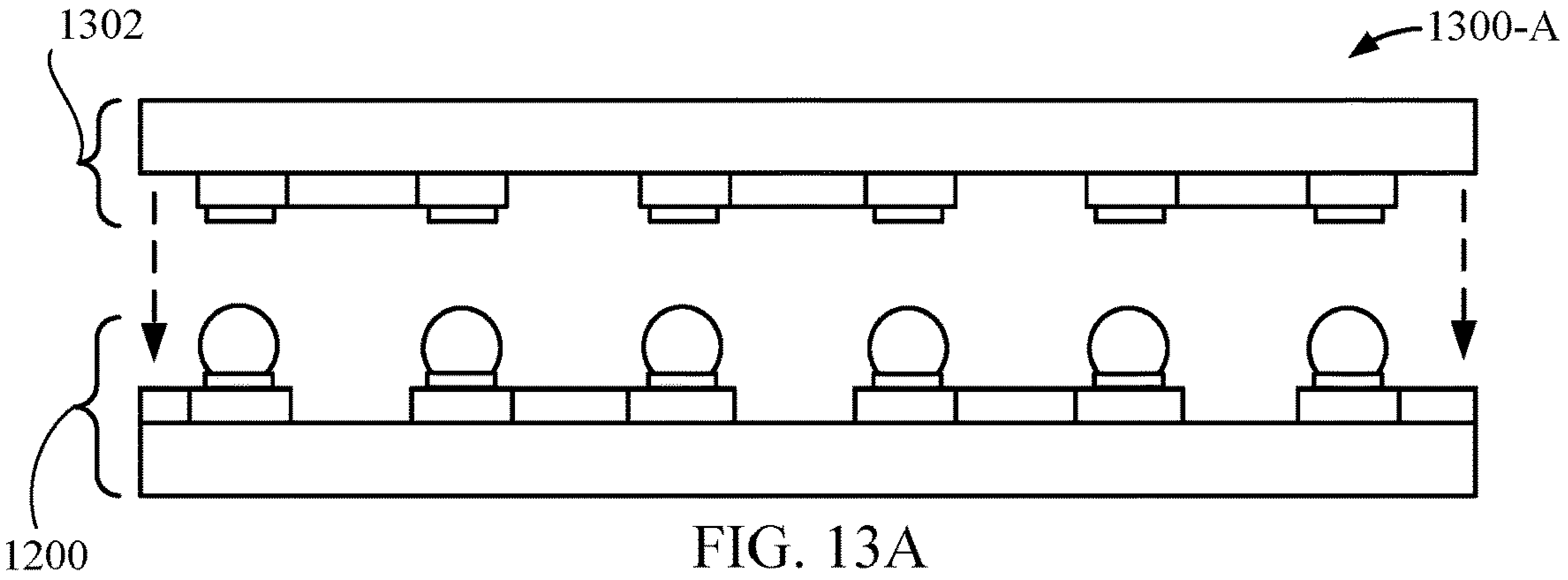


FIG. 13A

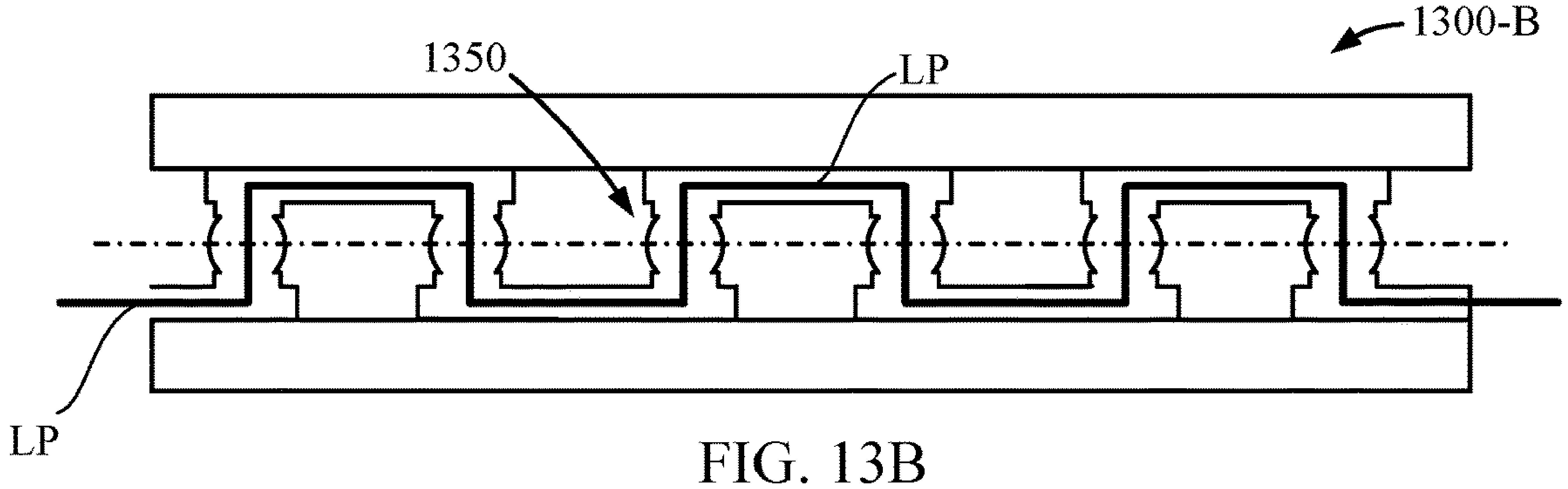


FIG. 13B

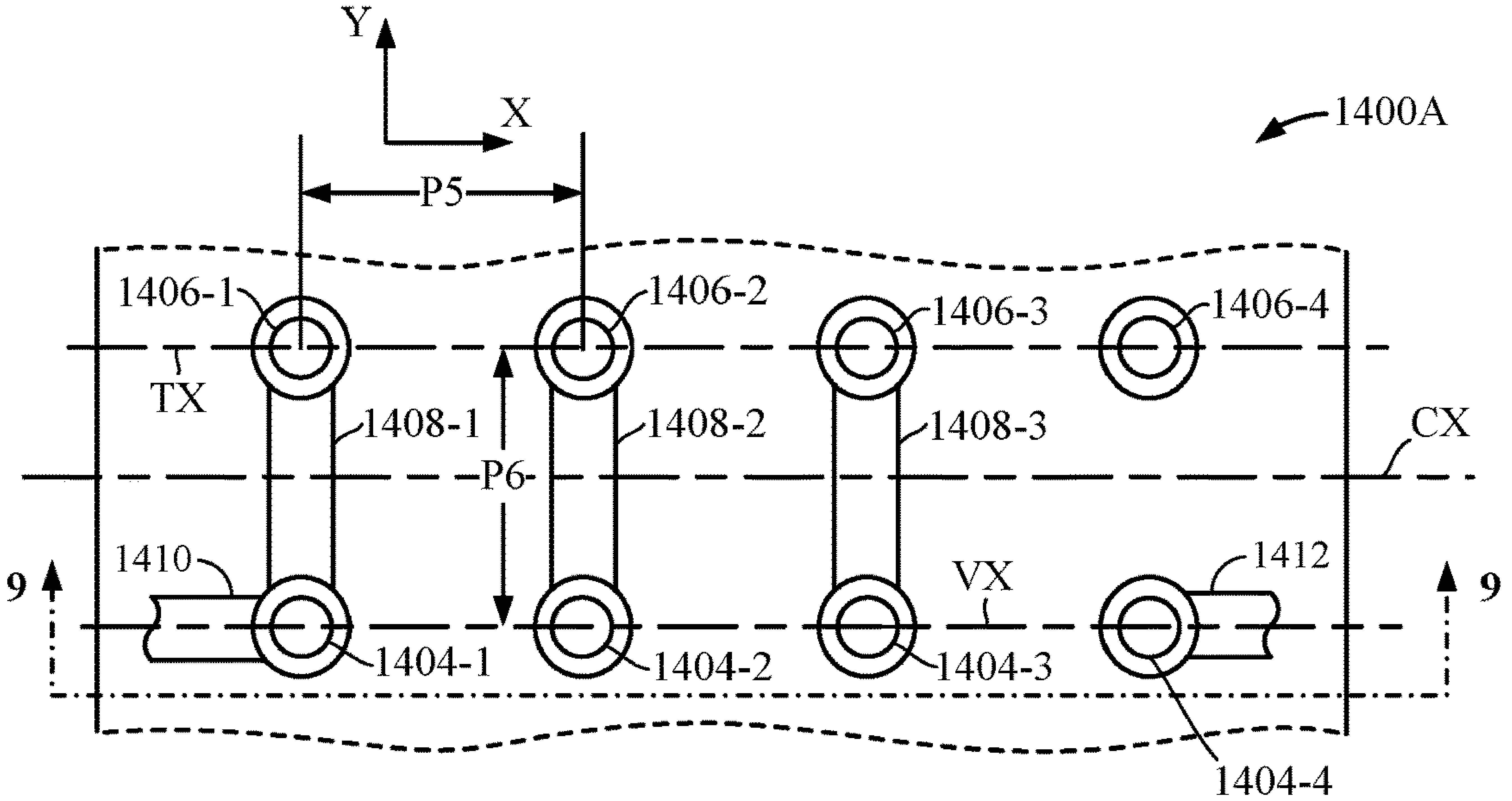


FIG. 14A

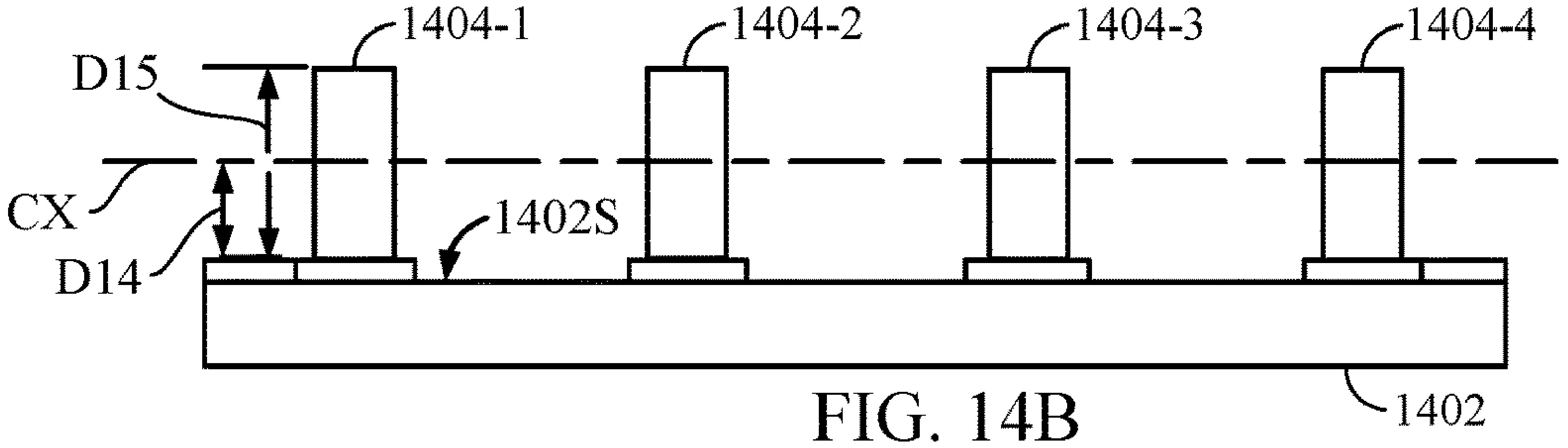


FIG. 14B

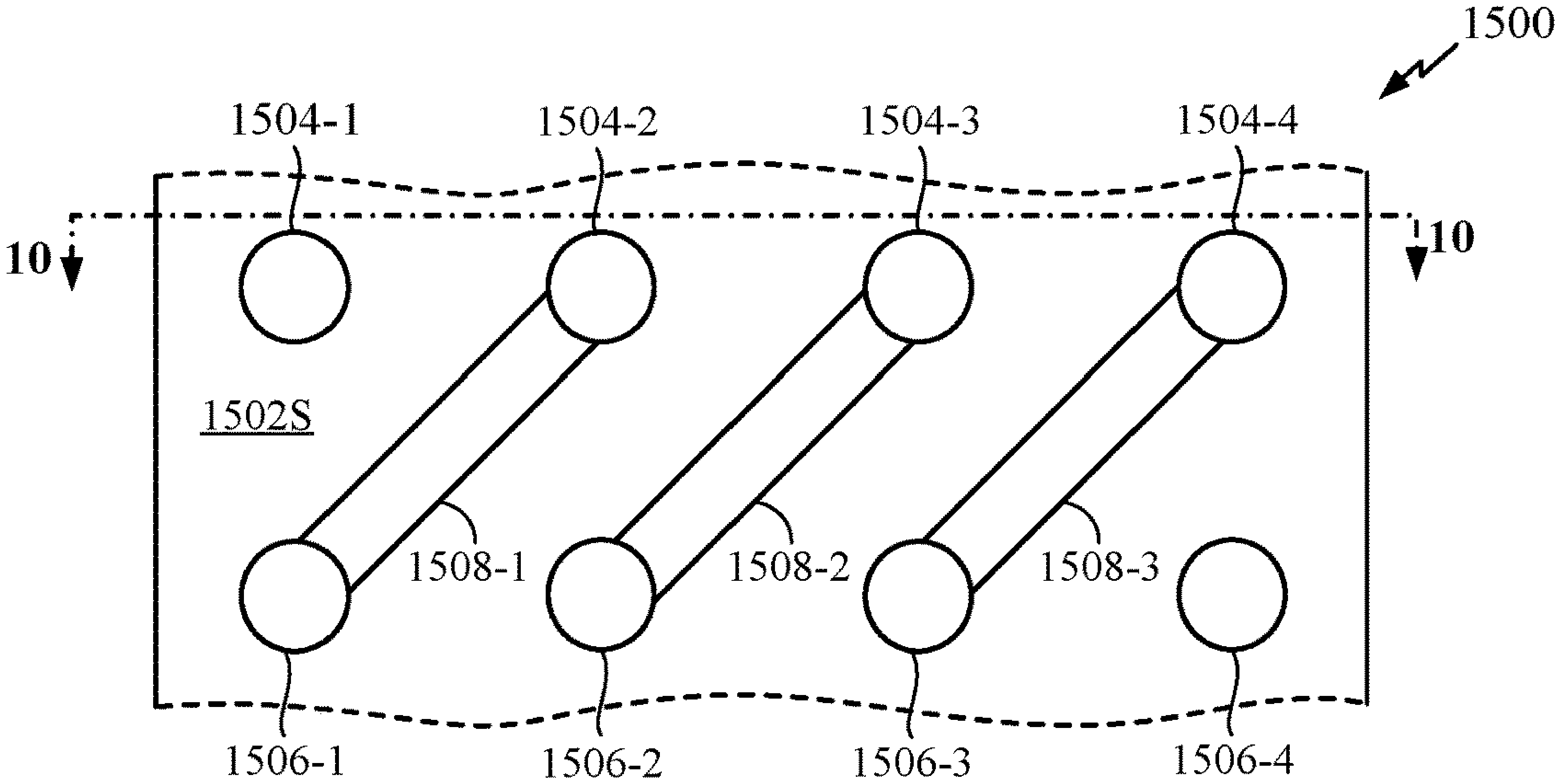


FIG. 15

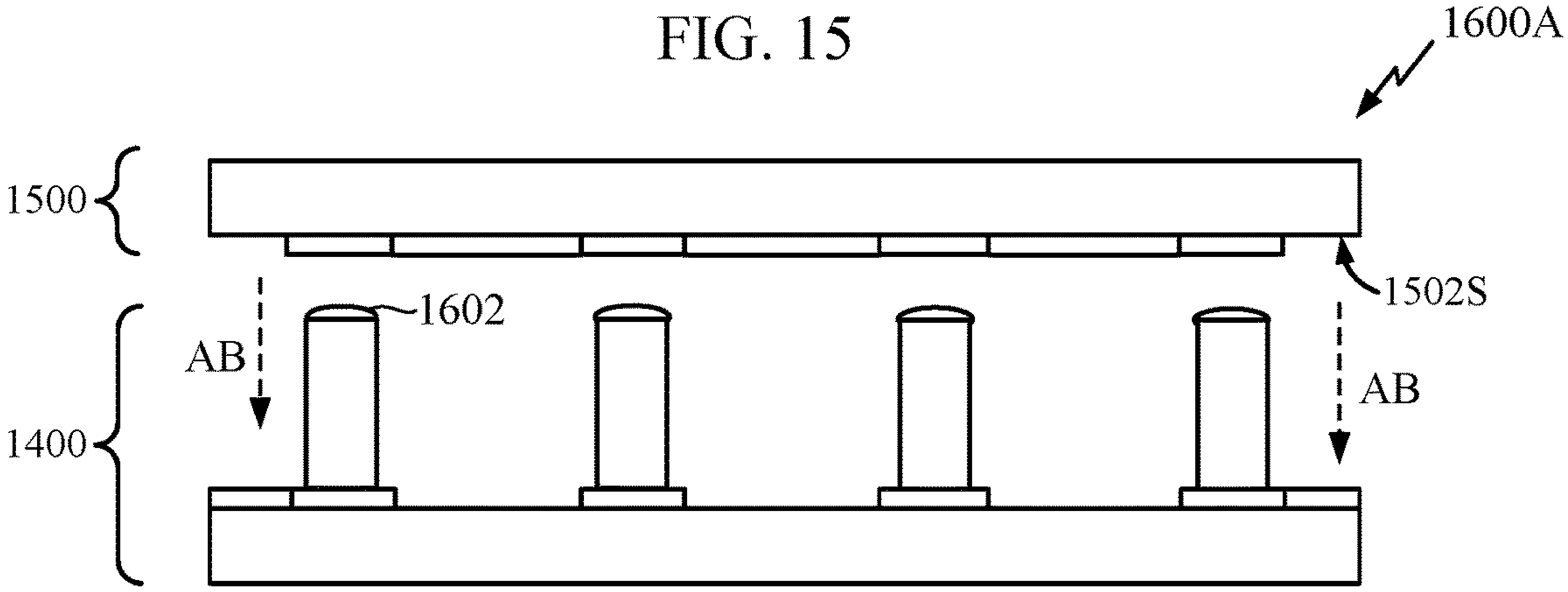


FIG. 16A

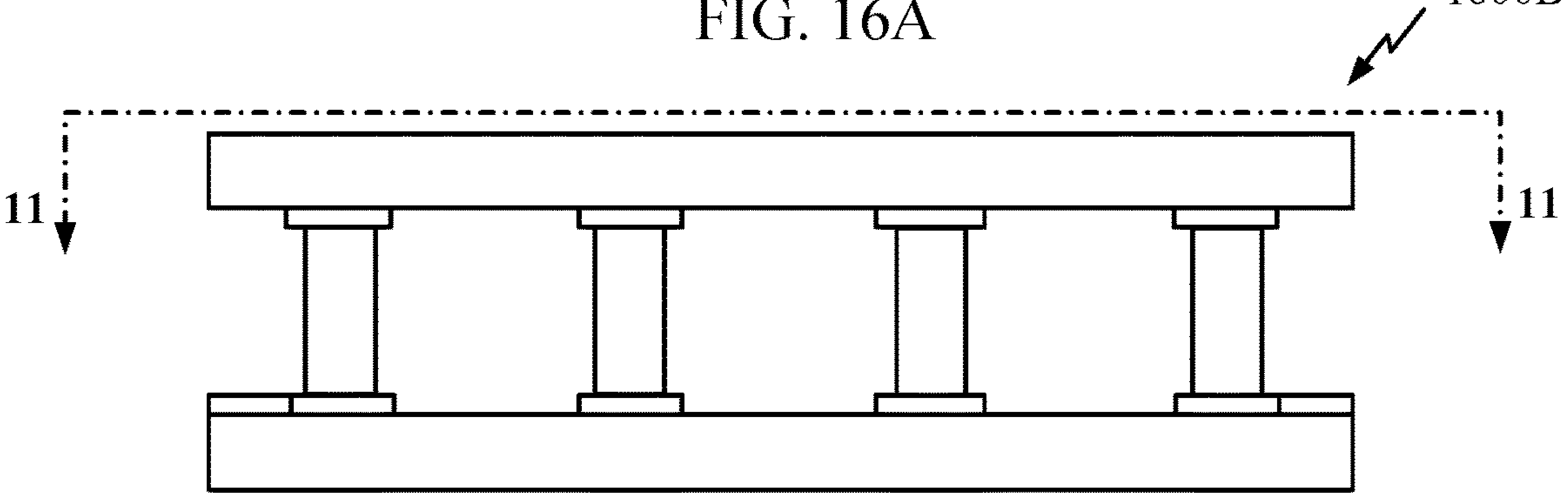


FIG. 16B

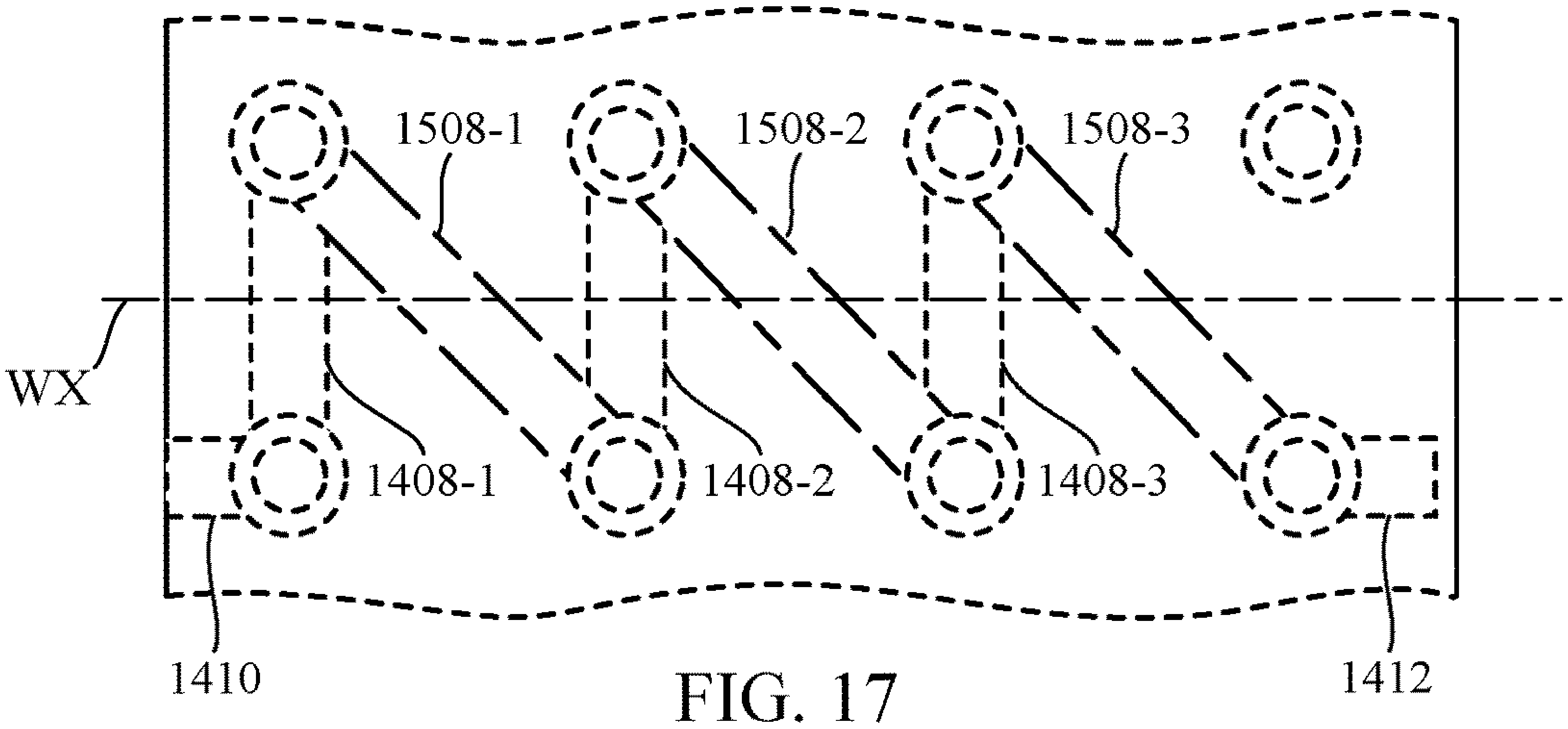

1508-1
1508-2
1508-3
WX
1408-1
1408-2
1408-3
1410
1412

FIG. 17

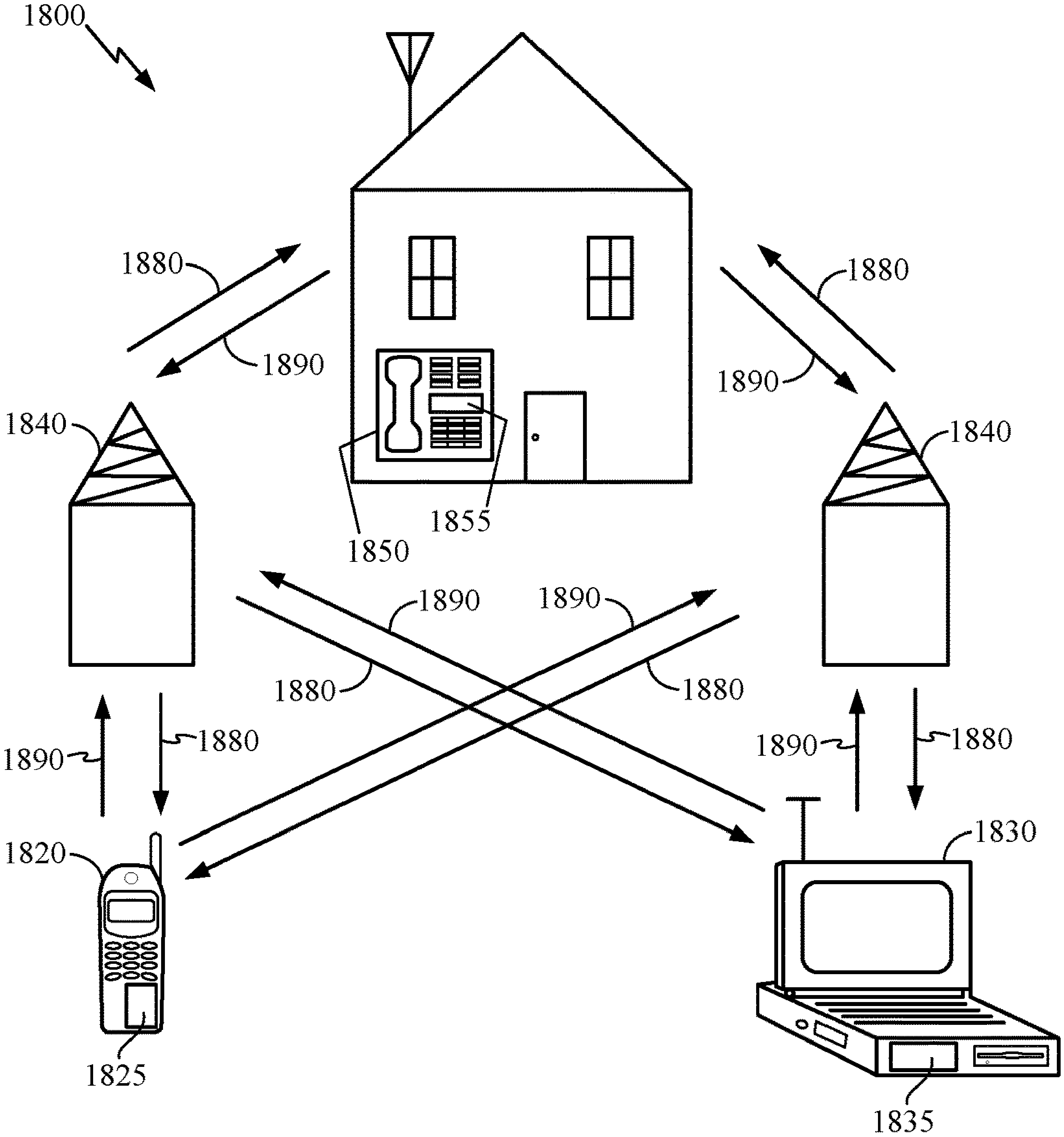

1800
1880
1890
1880
1890
1840
1840
1850
1855
1890
1890
1880
1880
1890
1880
1890
1880
1820
1830
1825
1835

FIG. 18

3D PILLAR INDUCTOR

CLAIM OF PRIORITY UNDER 35 U.S.C. § 120

The present application for Patent is a divisional of, and claims priority to, U.S. patent application Ser. No. 14/229,317, entitled "3D PILLAR INDUCTOR," filed Mar. 28, 2014, pending, assigned to the assignee hereof, and expressly incorporated herein by reference in its entirety.

FIELD OF DISCLOSURE

The present application is generally related to inductors and radiating elements within integrated circuit devices.

BACKGROUND

Inductors can be formed or installed on integrated circuit (IC) chips for various applications. Examples include inductors in series with power rails to filter current "spikes," e.g., from rapid switching of loads, and "LC" filters comprising various interconnects of inductors and capacitors.

One known IC chip inductor structure is the planar "zigzag" or "meander line" (hereinafter "meander") inductor. FIG. **1** shows one conventional planar meander inductor **100**, formed of a meander conductor **102** extending on the top plane of a substrate **104**. However, conventional planar meander inductors as shown in FIG. **1** can have certain shortcomings. One can be area, i.e., the product of L**1** and W**1**, the meander conductor **102** occupies on the surface of the substrate **104**. Another shortcoming can be a low value of its quality factor, Q, which is the ratio of the reactance, (ω×L), to the real resistance, R, due in part to the dielectric properties of the substrate **104**. The lower than preferred Q can have negative effects such as power consumption, which can reduce battery life and generate heat and, in applications such as LC filters, can reduce performance.

Another known IC chip inductor structure is a three-dimensional ("3D") structure known as a "through-glass-via" or "TGV" 3D inductor, such as the TGV 3D inductor **200** shown by FIGS. **2**A and **2**B. FIG. **2**A is a top view, from a direction normal to the top surface **202**A of a glass substrate **202**. FIG. **2**B is a cross-cut projection view from the FIG. **2**A cutting plane **1**-**1**. Referring to FIGS. **2**A and **2**B, the TGV 3D inductor **200** employs through glass vias (TGVs) **204** as vertical segments, and top and bottom traces **206** and **208**, respectively, as horizontal segments.

The TGV 3D inductor **200** can have, in some applications, a higher Q and higher inductance compared to a comparable FIG. **1** conventional planar meander inductor **100**. However, the related art TGV 3D inductor **200** can have certain shortcomings. One shortcoming is that the minimum pitch (i.e., TGV-to-TGV spacing), shown as P**1** and P**2** on FIGS. **2**A and **2**B, may be larger than desired, due to fundamental aspects of TGV technology. As a result, the TGV 3D inductor **200** often occupies a larger area or volume than preferred.

Accordingly, there is a need for a high Q, low surface area IC chip inductor.

SUMMARY

Various exemplary embodiments can also provide inductor structures having features and benefits that can include, but are not limited to, higher inductance per unit area, or per

unit volume, and higher Q, ease of fabrication and compatibility with known conventional IC design and fabrication techniques.

Example three-dimensional (3D) inductors in accordance with various exemplary embodiments may include a first base pad and a second base pad, spaced by a pitch. The first base pad and the second base pad may be arranged on a given base pad support surface. A first conducting member may be arranged, having a base aligned with and coupled to the first base pad, and having a top at a height above the first base pad. In an aspect, a second conducting member may have a base aligned with and coupled to the second base pad, and a top at the height above the second base pad. In an aspect, a first top pad may be arranged on a given top pad support surface above and facing the given base pad support surface, aligned with the first base pad and coupled to the top of the first conducting member. In a related aspect, a second top pad may be arranged on the given top pad support surface, aligned with the second base pad and coupled to the top of the second conducting member. In an aspect, a top pad interconnector may be formed on the given top pad support surface, coupling the first top pad to the second top pad.

In an aspect, the first conducting member, the first top pad, the top pad interconnector, the second top pad, and the second conducting members may be arranged to establish a meander current path, from the first base pad to the second base pad, within a reference plane normal to a plane of the given base pad support surface.

In a further aspect, the height and pitch of the first conducting member, the second conducting member, the third conducting member and the fourth conducting member may be configured wherein the meander current path establishes an inductor approximating a meander inductor, having four arms. The arm length of the approximated meander inductor may correspond to the height. The arm spacing may correspond to the pitch. The first base pad may be a first terminal and the second base pad may be a second terminal.

Example three-dimensional (3D) inductors in accordance with various exemplary embodiments may include a first row of conducting members and a second row of conducting members. The conducting members may each extending a height from a corresponding base pad on a given base pad support surface up to a corresponding top pad. The corresponding top pad may be on a given top pad support surface facing the given base pad support surface. In an aspect, the first row of conducting members and the second row of conducting members may be arranged parallel to, and on opposite sides of, a given winding axis. The given winding axis may be parallel to and between the given base pad support surface and the given top pad support surface. The base cross-connector may connect a base pad of a first conducting member in the first row, under the given winding axis, to a base pad of a first conducting member in the second row. In a further aspect, an adjacent turn link may extend from a top pad of the first conducting member in the second row, over the winding axis, to the top pad of a second conducting member in the first row, adjacent the first conducting member in the first row.

Example methods in accordance with various exemplary embodiments may provide a forming of a 3D inductor, and may include fabricating an inductor lower sub-assembly, fabricating an inductor top sub-assembly, and assembling the sub-assemblies. In an aspect, forming an inductor lower sub-assembly may include forming a first base pad and a second base pad, spaced by a pitch, on a given base pad support surface of a substrate, in addition to forming a first conducting member having a base aligned with and coupled to the first base pad. In an aspect, the first conducting member may have a top at a height above the first base pad. Methods may also include forming a second conducting member having a base aligned with and coupled to the second base pad, and a top at the height above the second base pad. In accordance with various exemplary embodiments, fabricating an inductor top sub-assembly may include forming, on a given top pad support surface of a given top support structure, a first top pad and a second top pad, spaced by the pitch. Methods may further include forming a top pad interconnector on the given top pad support surface, coupling the first top pad to the second top pad. Example methods may further include assembling the inductor top sub-assembly to the inductor lower sub-assembly to form the 3D inductor. In an aspect, the assembling may include aligning and coupling the first top pad and the second top pad, respectively, with the top of the first conducting member and the top of the second conducting member.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are presented to aid in the description of embodiments of the invention and are provided solely for illustration of the embodiments and not limitation thereof.

FIG. **1** is a plan view of a related art planar meander inductor.

FIG. **2**A is a top view of a related art TGV inductor.

FIG. **2**B is a projection, on the **1-1** cut plane, of the FIG. **2**A related art TGV inductor.

FIG. **3**A is a front view of a three-dimensional (3D) pillar meander inductor according to one or more exemplary embodiments, viewed from a projection parallel to an extending plane of the Cu pillar arms.

FIG. **3**B is an annotation of FIG. **3**A, showing a meander inductor current path through established by the 3D pillar meander inductor.

FIG. **4**A is a projection, on the FIG. **3**A cutting plane **3-3**, showing an example alignment and pitch of the Cu pillars of the 3D pillar meander inductor and their respective pillar base interconnectors according to one example] pillar base interconnection pattern.

FIG. **4**B is a projection, on the FIG. **3**A cutting plane **4-4**, showing Cu pillar top pads of the 3D pillar inductor, and their respective pillar top interconnectors according to one example pillar top connection pattern.

FIGS. **5**A-**5**H show, from the FIG. **3**A front view, one snapshot sequence of example operations in one process of fabricating, on a lower substrate, a 3D pillar meander inductor lower sub-assembly for subsequent assembly with a corresponding 3D pillar meander inductor top sub-assembly to one or more exemplary embodiments.

FIG. **6** is a plane view, from the FIG. **5**H projection **5-5**, showing an alignment of the Cu pillars extending up from the lower substrate of the 3D pillar meander inductor lower sub-assembly.

FIG. **7**A is a plan view of one example arrangement of pillar top pads and pillar top interconnectors of one 3D pillar meander inductor top sub-assembly, before being flipped over for assembly with the FIG. **5**H 3D pillar meander inductor lower sub-assembly.

FIG. **7**B is a front view from the FIG. **7**A projection **6-6**, after being flipped over for assembly with the FIG. **5**H 3D pillar meander inductor lower sub-assembly.

FIGS. **8**A-**8**B show a snapshot sequence of assembly of the FIG. **7**A-**7**B 3D pillar meander inductor top sub-assembly onto the FIG. **5**H 3D pillar meander inductor lower sub-assembly to form a 3D meander inductor according to one or more exemplary embodiments.

FIGS. **9**A-**9**B show a snapshot sequence of example operations in assembling a modified 3D pillar meander inductor top sub-assembly, having a top portion of the Cu pillars, onto a modified 3D pillar meander inductor lower sub-assembly having a lower portion of the Cu pillars, to form a 3D meander inductor according to one or more exemplary embodiments.

FIG. **10** shows a logic diagram of one flow of example operations in one process of fabricating a 3D pillar meander inductor according to one or more exemplary embodiments.

FIG. **11**A is a front view of a 3D pillar rectangular spiral inductor according to one or more exemplary embodiments, viewed from a projection normal to the plane of the lower substrate.

FIG. **11**B is a projection, on the FIG. **11**A cutting plane **7-7** showing one example arrangement of Cu pillars and base pad interconnection for one example 3D pillar rectangular spiral inductor in accordance with various exemplary embodiments.

FIG. **11**C is a projection, on the FIG. **11**A cutting plane **8-8**, showing one example arrangement of Cu pillar top pads and respective pillar top pad interconnectors, one example 3D pillar rectangular spiral inductor in accordance with various exemplary embodiments.

FIG. **12** is a front view of one 3D solder ball meander inductor lower sub-assembly according to one exemplary alternative embodiment.

FIGS. **13**A-**13**B show a snapshot second of one example operation in assembling a 3D solder ball meander inductor top sub-assembly onto a modified 3D solder ball meander inductor lower sub-assembly, to form a 3D solder ball meander inductor according to one exemplary alternative embodiments.

FIG. **14**A is a plan view of a lower sub-assembly of a 3-turn Cu pillar coil inductor in accordance with one or more exemplary embodiments.

FIG. **14**B is a front view, from the FIG. **14**A projection **9-9**.

FIG. **15** is a plan view of one example Cu pillar coil inductor upper or top sub-assembly configured for assembly with the FIG. **14**A-**14**B pillar coil inductor lower sub-assembly **1400**, to form a 3-turn pillar coil inductor according to one or more exemplary embodiments.

FIGS. **16**A-**16**B shows a snapshot of one example operation in assembling the FIG. **15** pillar coil inductor top sub-assembly onto the FIG. **14**A-**14**B pillar coil inductor lower sub-assembly to form a 3-turn pillar coil inductor according to one or more exemplary embodiments

FIG. **17** is a top view of the 3-turn pillar coil inductor of FIG. **16**B from projection **11-11** showing, by hidden lines, pillar cross connectors crossing under the winding axis WX and the pillar adjacent turn links passing, diagonally, over the winding axis WX.

FIG. **18** shows one example functional schematic of one example personal communication and computing device in accordance with one or more exemplary embodiments.

DETAILED DESCRIPTION

Aspects of the invention are disclosed in the following description and related drawings directed to specific exemplary embodiments. Alternate embodiments may be devised without departing from the scope of the invention. In certain described example implementations, instances are identified where various component structures and portions of operations can be taken from known, conventional techniques, and then arranged in accordance with one or more exemplary embodiments. In such instances, internal details of the known, conventional component structures and/or portions of operations are omitted to help avoid potential obfuscation of inventive concepts.

The terminology used herein is only for the purpose of describing particular embodiments and is not intended to be limiting of embodiments of the invention.

The word "exemplary," as used herein, means "serving as an example, instance, or illustration." Accordingly, the term "exemplary embodiment," as used herein, means an embodiment serving as an example, instance, or illustration, but that is not necessarily preferred or advantageous over other embodiments. Likewise, it will be understood that the term "embodiments of the invention," as used herein in reference to a feature, advantage or mode of operation, does not mean that all embodiments of the invention include the discussed feature, advantage or mode of operation.

As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises", "comprising," "includes" and/or "including", when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Certain embodiments are described in terms of operations and steps, for example, in or relating to various processes of design and fabrication. It will be understood, that except in instances where explicitly stated or where made clear from a particular context, that the described order of such operations and steps is only for purposes of example, and is not necessarily limiting of the order of operations or steps that may be applied in practices according to various exemplary embodiments

Further, certain embodiments are described in terms of operations, steps, actions and sequences of operations, steps and actions that can performed by or under control of, for example, a computing device or elements of a computing device. It will be understood by persons of ordinary skill, upon reading this disclosure, that such operations, steps, actions, sequences and other combinations therefore can be performed by, or under control of specific circuits (e.g., application specific integrated circuits (ASICs)), by program instructions being executed by one or more processors, or by a combination of both.

Accordingly, it will be appreciated by such persons that operations, steps, actions, sequences and other combinations thereof can be embodied entirely within any form of computer readable storage medium having stored therein a corresponding set of computer instructions that, upon execution, can cause an associated processor to perform, directly or indirectly, operations, steps, actions, sequences and other combinations described herein. Thus, the various aspects of the invention may be embodied in a number of different forms, all of which are contemplated to be within the scope of the claimed subject matter.

Throughout this disclosure, the term "pad" means a conducting structure disposed on a described surface, having a thickness within a range including, but not limited to, the range of thickness encompassed by structures within the ordinary and customary meaning of "pad" within the integrated circuit (IC) and IC packaging arts.

The term "conducting member" means, as used throughout this disclosure, a conducting structure, e.g., a conducting pillar, post, or ball, having a base or bottom surface aligned with and coupled to, or configured to be aligned with and coupled to, a corresponding "base pad," and having a top surface spaced a "height" above the base, aligned with and coupled to, or configured to be aligned with and coupled to a corresponding pad designated a "top pad."

One example three-dimensional (3D) inductor according to various exemplary embodiments includes a first base pad and a second base pad, spaced from one another by a pitch, disposed on a given base pad support surface. The given base pad support surface may, for example, be an assigned top surface area of a given lower or base substrate. In an aspect, a first conducting member (e.g., a metal pillar, post or solder ball) may be aligned with and coupled to the first base pad, and a second conducting member may be aligned with and coupled to the second base pad. In a further aspect, a top of the first conducting member may be coupled to a first top pad on a given top pad support surface, which may be spaced above and facing the base pad support surface. The first top pad may be above and aligned with the first base pad. In a further aspect, a top of the second conducting member may be coupled to a second top pad on the given top pad support surface, and the second top pad may be above and aligned with the second base pad. A top pad interconnector, on the top pad support surface, may couple the first top pad to the second top pad.

In an aspect, the first conducting member, the first top pad, the top pad interconnector, the second top pad and the second conducting member may establish a meander current path within a plan normal to the given base pad support surface.

As will be appreciated by persons of ordinary skill in the art to which exemplary embodiments pertain, the height and pitch of the first conducting member and the second conducting member may be configured wherein the meander current path approximates a meander inductor having two arms. The arm length of the approximated meander inductor may correspond to the height, and the arm spacing may correspond to the pitch. In an aspect, the first base pad may be a first terminal and the second base pad may be a second terminal.

In one example, the given top pad support surface may itself be a bottom surface of another substrate above the base or lower substrate. For example, without limitation, one given top pad support surface may be a bottom surface a substrate supporting, on its top surface, an IC chip in a flip-chip configuration. As another example, without limitation, one given top pad support surface may be an active chip surface of an IC chip supported in a flip-chip configuration by the given base or lower substrate.

In an aspect, in example 3D inductors according to various exemplary embodiments, each of the conducting members may be a metal pillar. For example, the first conducting member may be a metal first pillar, and the second conducting member may be a metal second pillar. As a more particular example, the first conducting member may be a first copper (Cu) pillar and the second conducting member may be a second Cu pillar.

In an aspect, the top pad interconnector may be a first top pad interconnector, and the 3D inductor may further comprise a third base pad and a fourth base pad on the given base pad support surface. In a further aspect, the first base pad, the second base pad, the third base pad and the fourth base pad may be aligned along a linear axis and spaced from one another by the pitch.

In another aspect, a base pad interconnector may be provided on the given base pad support surface coupling the first base pad and the second base pad. In combination, a third conducting member may be aligned with and coupled to the third base pad, and a fourth conducting member aligned with and coupled to the fourth base pad. The third conducting member and the fourth conducting member may have the same height as the first conducting member and the second conducting member. In another aspect, a third top pad and a fourth top pad may be disposed on the given top pad support surface. The third top pad may be aligned with and coupled to a top of the third conducting member, and the fourth top pad may be aligned with and coupled to a top of the fourth conducting member. In an aspect, a second top pad interconnector may be supported on the given top pad support surface, coupling the third top pad to the fourth top pad.

In an aspect, the first conducting member, the first top pad, the first top pad interconnector, the second top pad and the second conducting member, the second base pad, the base pad interconnector, the third base pad, the third conducting member, the third top pad, the fourth top pad, and the fourth conducting member may establish a meander current path. In an aspect, the established meander current path may be within a plane normal to the given base pad support surface, from the first base pad to the fourth base pad.

As will be appreciated by persons of ordinary skill in the art from reading this disclosure, the height and pitch of the first conducting member, the second conducting member, the third conducting member and the fourth conducting member may be configured wherein the meander current path establishes an inductor approximating a meander inductor having four arms. The approximated meander inductor may have an arm length corresponding to the height and an arm spacing corresponding to the pitch. The first base pad may be a first terminal and the fourth base pad may be a second terminal.

FIG. **3**A shows a front view of one 3D pillar inductor structure **300** according to one exemplary embodiment. As shown by FIG. **3**B, the 3D pillar inductor structure **300** provides a 3D pillar meander inductor **350** that, according to one exemplary embodiment, establishes a meander current path CP. In an aspect, the meander inductor **350** includes six arms, each formed, respectively, by one of the example metal pillars **302-1**, **302-2** . . . **302-6** (collectively "metal pillars **302**"). The metal pillars **302** may extend a pillar height D**1** from a base pad support surface **304**S of a lower substrate **304** up to a top pad support surface **306**S of a top support structure **306**. It will be understood that terms such as "lower" and "upper" refer to a top-to-bottom order on the sheet of FIGS. **3**A-**3**B, and pillar "height" means extension from the base pad support surface **304**S, and these are not necessarily related to orientation within a larger reference frame (e.g., earth). It will be appreciated that the meander current path CP is within a plane normal to the base pad support surface **304**S.

FIG. **4**A is a plan view, from the FIG. **3**B projection **2-2**, showing the pitch P**3** and arrangement of the metal pillars **302** on the base pad support surface **304**S and their particular interconnections. FIG. **4**B is a plan view, from the FIG. **3**B projection **3-3**, showing particular interconnection of the tops of the metal pillars **302** on the top pad support surface **306**S of the top support structure **306**. In describing example aspects of the 3D pillar inductor structure **300**, the metal pillars **302-1**, **302-2** . . . **302-6** may be referred to, individually, as a metal first pillar **302-1**, a metal second pillar **302-2**, a metal third pillar **302-3**, a metal fourth pillar **302-4**, a metal fifth pillar **302-5** and a metal sixth pillar **302-6**.

In an aspect, the metal pillars **302** may be formed of copper (Cu). Subsequent description of examples using Cu for the conductive pillars **302** will, for brevity, refer to the metal pillars **302** as "Cu pillars" **302**. In describing example aspects of the 3D pillar inductor structure **300** using Cu pillars **302**, the Cu pillars **302** may be referred to, individually, as a first Cu pillar **302-1**, a second Cu pillar **302-2**, a third Cu pillar **302-3**, a fourth Cu pillar **302-4**, a fifth Cu pillar **302-5** and a sixth Cu pillar **302-6**. Description referring to Cu pillars **302**, however, is not intended to limit the exemplary embodiments to metal pillars **302** formed of Cu. On the contrary, exemplary embodiments contemplate metal pillar **302** of alternative high conductance metals such as, without limitation, aluminum (Al) and various copper alloys. In addition, persons of ordinary skill in the art, upon reading this disclosure, can adapt description referring to Cu pillars **302** to practices of the exemplary embodiments using alternative metals, such as Al, without undue experimentation.

Referring to FIG. **4**A, on the base pad support surface **304**S of the lower substrate **304** may be a linear arrangement, along the axis AX, of base pads **308-1**, **308-2** . . . **308-6** (collectively "base pads **308**") equally spaced by pitch P**3**. Each of the base pads supports a corresponding one of the Cu pillars **302**. In describing example aspects of the 3D pillar inductor structure **300**, base pads **308-1**, **308-2** . . . **308-6** may be referred to, individually, as a first base pad **308-1**, a second base pad **308-2**, a third base pad **308-3**, a fourth base pad **308-4**, a fifth base pad **308-5** and a sixth base pad **308-6**.

A first terminal TA can connect to the first base pad **308-1** and a second terminal TB can connect to the sixth base pad **308-6**. The first and second terminals TA and TB are not necessarily specifically structured as terminals. For example, "TA" and "TB" may simply be reference names applied to the first base pad **308-1** and sixth base pad **308-6**, respectively. In addition, the first and second terminals TA and TB are both on the base pad support surface **304**S because the example quantity of metal pillars **302**, which is six, is even. It will be understood that if an odd number of metal pillars **302** is selected, one of the first and second terminals TA and TB may be on the supporting surface **304**A and the other on the top pad support surface **306**S.

Referring still to FIG. **4**A, also on the base pad support surface **304**S a base pad first interconnector **310-1** can connect the second base pad **308-2** to the third base pad **308-3**. Similarly, a base pad second interconnector **310-2** can connect the fourth base pad **308-4** to the fifth base pad **308-5**. The base pad first interconnector **310-1** and the base pad second interconnector **310-2** will be collectively referred to as "base pad interconnectors **310**." The base pad interconnectors **310** may be formed, for example, of Cu or another good conducting metal. The above-described pattern by which the base pad interconnectors **310** connect the base pads **308** can be referred to as a "base pad interconnection pattern."

FIG. **4**B is a plan view from the FIG. **3**B cut plane **3-3** of the top pad support surface **306**S, showing six pillar top pads, **312-1**, **312-2** . . . **312-6** (collectively "top pads" **312**), arranged along axis AX' in alignment with base pads **308**. In describing example aspects of the 3D pillar inductor structure **300**, top pads **312-1**, **312-2** . . . **312-6** may be referred to, individually, as a first top pad **312-1**, a second top pad **12-2**, a third top pad **312-3**, a fourth top pad **312-4**, a fifth top pad **312-5** and a sixth top pad **312-6**. A top pad first interconnector **314-1** connects the first top pad **312-2** to the second top pad **312-2**. A top pad second interconnector **314-2** connects the third top pad **312-3** to the fourth top pad **312-4**, and a top pad third interconnector **314-3** connects the fifth top pad **312-5** to the sixth top pad **312-6**. The top pad first interconnector **314-1**, top pad second interconnector **314-2** and top pad third interconnector **314-3** will be collectively referred to as "top pad interconnectors **314**." The top pad interconnectors **314** may be formed, for example, of Cu or another good conducting metal. The above-described pattern by which the top pad interconnectors **314** connect the top pads **312** can be referred to as a "top pad interconnection pattern."

Referring to FIGS. **3A-3B**, the above-described arrangement of the metal pillars **302**, with their base pads **308** interconnected in the described base pad interconnection pattern, and their top pads **312** interconnected in the described top pad interconnection pattern, provides the meander inductor **350** with the meander current path CP. As previously described, the meander current path CP may be within a plane normal to the base pad support surface **304**S. In an aspect, the height D**1** of the metal pillars **302** and the pitch P**3** may be configured wherein the meander current path CP establishes an inductor approximating a meander inductor having six arms. The arm length of the approximated meander inductor may correspond to D**1** and the arm spacing may correspond to P**3**. The first base pad **308-1** may be a first terminal and the sixth base pad **308-6** may be a second terminal.

The above-described 3D pillar meander inductor **350** shows its metal pillars **302** arranged along the linear axis AX. This is only one example, and is not intended as a limitation on any of the exemplary embodiments. Additional aspects having metal pillars and other conducting members arranged over an X-Y area, for example, to form a 3D coil inductor, are described later in this disclosure.

Referring again to FIG. **4**A, the metal pillars **302** are shown equally spaced, by pitch P**3**. This is only for purposes of example. In one alternative aspect, the metal pillars **302** may be unequally spaced (not explicitly shown in the figures). Further, the metal pillars **302** are shown with a circular cross-section. The circular cross-section, though, is only an example and not a limitation.

Regarding the top support structure **306**, FIG. **3**A shows it as a substrate that supports, in a flip-chip arrangement, an IC chip arbitrarily labeled "Chip X." It will be understood that the top supporting structure **306** is only one example. Practices according to various embodiments include, for example, using a surface of an integrated circuit chip, such as "Chip X" to perform the described functions of the top pad support surface **306**S.

Referring to FIGS. **3A-3**B and **4A-4**B, the quantity of six metal pillars **302** is only for purposes of example, and is not intended to limit the quantity of metal pillars **302** that exemplary embodiments may comprise. For example, as will be understood from reading this disclosure in its entirety, structures in accordance with FIGS. **3A-3**B can be implemented having only three or less metal pillars **302** or, for example, seven or more metal pillars **302**.

Referring to FIG. **3**B, in an aspect, a distributed space (shown but not separately labeled) may exist between the metal pillars **302**, spanning from the base pad supporting surface **304**S of the lower substrate **304** up to the top pad supporting surface **306**S of the top support structure **306**. In an aspect, this distributed space may be filled, for example, with air. In a further aspect, the distributed space may be filled with a low-loss dielectric material. In another aspect, the distributed space may be filled with magnetic materials.

It will be understood that 3D meander inductors according to the exemplary embodiments can consist of fewer turns than shown by the example 3D pillar meander inductor **350**. For example, a "one turn" (not separately labeled in the FIG. 3D pillar meander inductor can be implemented using only the metal first pillar **302-1**, metal second pillar **302-2**, and top pad first interconnector **314-1**. One terminal of this "one-turn" 3D meander inductor can be the inductor first terminal lead TA (or the first base pad **308-1**), and the other can be the second base pad **308-2**. In this example, the metal first pillar **302-1**, the first top pad **312-1**, the first top pad interconnector **314-1**, and the metal second pillar **302-2** may form a meander current path (visible in FIG. **3**B, but not separately labeled). This one-turn example is only one implementation. Persons of ordinary skill in the art having possession of this disclosure can readily identify, within the 3D pillar meander inductor **350**, other of its constituent structures that may be used as a one-turn 3D pillar meander inductor. In addition, it may become apparent to such persons upon reading this disclosure that the 3D pillar meander inductor **350** may be supplemented with additional metal pillars (not explicitly shown in FIGS. **3A-3**B or FIGS. **4A-4**B), and corresponding additional pillar top pad interconnectors and pillar base pad interconnectors, in general patterns as disclosed.

Example operations in an illustrative process for fabricating 3D pillar meander inductors according to various exemplary embodiments will now be described in greater detail.

Referring to FIG. **5**A, one starting structure **500**-A can comprise a lower substrate **502** having a supporting surface **502**S. The lower substrate **502** may be, in example implementations, a region or portion of a larger lower substrate (not fully visible in FIG. **5**A).

The starting structure **500**-A will be described assuming it is configured for fabricating the FIGS. **3A-3**B and **4A-4**B pillar inductor structure **300**, to focus on concepts without possible obfuscation by description of another example structure implementation. Accordingly, for this example, the starting structure **500**-A has, on the supporting surface **502**S, six base pads **504-1**, **504-2** . . . **504-6** (collectively "base pads" **504**) arranged along a linear alignment axis (not visible in FIG. **5**A). The linear alignment axis may be for example, the FIG. **4**A AX. In an aspect, the base pads **504** may be spaced by a pitch (shown but not separately labeled) that is assumed as P**3**. In describing example aspects, base pads **504** may be referred to, individually, as first base pad **504-1**, second base pad **504-2**, third base pad **504-3**, fourth base pad **504-4**, fifth base pad **504-5** and sixth base pad **504-6**.

Also on the supporting surface **502**S of the lower substrate **502**, base pad first interconnector **506-1** is configured to connect the second base pad **504-2** to the third base pad **504-3**, and a base pad second interconnector **506-2** is configured to connect the fourth base pad **504-4** to the fifth base pad **504-5**. This arrangement of the base pad first interconnector **506-1** and base pad second interconnector **506-2** therefore connects the base pads **504** according to the base pad interconnection pattern described for the lower FIG. **3A-3**B base pads **308**. A conductor labeled "TR," shown on the support surface **502**S as connected to the first base pad **504-1**, may be included as a first terminal. A conductor labeled "TS," also shown on the support surface **502**S as connected to the base pad **504-6**, may be included as a second terminal.

Referring to FIG. **5**B, operations according to one process may include depositing a passivation layer **508** over the FIG. **5**A starting structure **500**-A to form the in-process structure **500**-B. The passivation layer **508** may be, for example, SiO_2. However, SiO_2 is only one example material for the passivation layer **508**. Persons of ordinary skill in the art, having view of the present disclosure, may identify various alternatives. The passivation layer **508** may be deposited according to conventional passivation layer techniques, not necessarily particular to the exemplary embodiments. Therefore, further detailed description of the technique for depositing the passivation layer **508** is omitted. The thickness (shown, but not separately labeled) of the passivation layer **508** may be, at least in part, application-specific. Persons of ordinary skill in the art, though, facing a specific application and having read the present disclosure in its entirety, can readily determine the appropriate thickness or range of thicknesses for the passivation layer **508**, without undue experimentation.

Referring to FIG. **5**C, after depositing the passivation layer **508**, an etching or other known removal operation may be performed to expose top surface areas **510** of the base pads **504**, as shown by in-process structure **500**-C. The exposed top surface areas **510**, in an aspect, are sites for subsequent depositing of Cu pillars (not shown in FIG. **5**C), for example, corresponding to the metal pillars **302** of the FIG. **3**A-**3**B pillar inductor structure **300**. The exposed top surface areas **510** may therefore dimensioned according to the diameter of the Cu pillars.

Referring to FIG. **5**D, after the top surface areas **510** of the base pads **504** are exposed, in-process structure **500**-D may be formed by depositing a seed layer **512** on a top surface (shown but not separately labeled) of the passivation layer **508**. As shown, the seed layer **512** may cover, in particular, the exposed top surface areas **510**. A function of the seed layer **512** is to assist in Cu (or alternative metal) electroplating of pillars on the exposed surface areas, as will be described in reference to later figures in this FIG. **5**A-**5**H snapshot sequence. The seed layer **512** may comprise, for example, Cu, titanium (Ti), tantalum (Ta) or one or more alternatives that may become apparent to persons of ordinary skill upon reading this disclosure. The seed layer **512** may be deposited by, for example, conventional techniques including, but not limited to, chemical vapor deposition (CVD), plasma vapor deposition (PVD), or alternative techniques that may become apparent to such persons upon reading this disclosure. The thickness (shown, but not separately labeled) of the seed layer **512** may be, at least in part application-specific. Persons of ordinary skill, though, can determine an application appropriate thickness of the seed layer **512** without undue experimentation by applying conventional techniques in view of the present disclosure. Further detailed description of the thickness is therefore omitted. The areas of the seed layer **512** directly on the exposed top surface areas **510**, of which one representative example is labeled "514" will support pillars that deposited in subsequent operations.

Referring next to FIG. **5**E, a mold layer **516** of thickness D**5** may then be deposited over the seed layer **512**, forming in-process structure **500**-E. The mold layer **516** may comprise, but is not limited to SiO_2. Alternatives to SiO_2 may become apparent to persons of ordinary skill upon reading this disclosure. The thickness D**5** of the mold layer **516**, in an aspect, can be substantially the same as a desired length (height) of the metal pillars (e.g., the metal pillars **302** of FIGS. **3**A-**3**B. In a further aspect, the mold layer **516** may be formed with a thickness D**5** greater than the desired metal pillar height to provide, for example, for depositing an inter-metallic compound (IMC) (not shown in FIG. **5**E) as, described later in greater detail.

Referring to FIG. **5**F, a masking and etching of pillar recesses **518** into the mold layer **516** may form in-process structure **500**F having a pillar mold **520**, with its pillar recesses **518** aligned with areas of the seed layer **512** on the previously exposed top surface areas **510**. The pillar recesses **518** may be shaped and dimensioned according to the desired pillars, e.g., metal pillars **302** of FIGS. **3**A-**3**B. Regarding techniques etching the pillar recesses **518**, a person of ordinary skill in the art having possession of this disclosure can select and adapt a conventional etching technique to perform this etching, without undue experimentation. Further detailed description is therefore omitted.

Referring to FIG. **5**G, after forming the pillar mold **520**, a metal, for example copper (Cu), or another conductor may be deposited to a height D**6** in the pillar recesses **518**. For purposes of example, it will be assumed that the deposited conductor is Cu. A result of the depositing is therefore a plurality of encased Cu pillars **522**, as shown by the in-process structure **500**-G. The depositing of the Cu (and various alternative metals) can be done, for example, by application of conventional electroplating techniques. The height D**6** to which the Cu is deposited can be D**5**, i.e., it can completely fill (not shown) the pillar recesses **518**. In one alternative aspect, the Cu may be deposited to a shallower depth (as shown), to allow, for example, a follow-on depositing of the previously mentioned IMC.

Referring next to FIG. **5**H, the pillar mold **520** may be removed to provide the in-process structure **500**-H. The in-process structure **500**-H may comprise the lower substrate **502** supporting, on base pads **504**, six Cu pillars, **522-1**, **522-2** . . . **522-6** (collectively, the "Cu pillars **520**," a label not explicit in the figures). In describing example aspects, Cu pillars **520** may be referred to, individually, as first Cu pillar **520-1**, second Cu pillar **520-2**, third Cu pillar **520-3**, fourth Cu pillar **520-4**, fifth Cu pillar **520-5** and sixth Cu pillar **520-6**.

For convenient reference to FIG. **5**H in subsequent sections of this disclosure, the tops, i.e., distal ends of the Cu pillars **522** will be generically referred to as "pillar tops **522**A", of which one representative example is labeled on the first Cu pillar **522-1**.

The above-described fabrication process connects the base pads **504** according to the base pad connection pattern of the 3D pillar meander inductor **350** of FIGS. **3**A-**3**B. This example in-process structure **500**-H will be referred to as a 3D pillar meander inductor "lower sub-assembly" **500**-H.

FIG. **6** is top view, from the FIG. **5**H projection **5-5**, showing the Cu pillars **522** spaced by pitch P**3** and aligned along the axis AX.

FIG. **7**A is a plan view of one example 3D pillar meander inductor top sub-assembly **700** configured for assembly with the 3D pillar meander inductor lower sub-assembly **500**-H, to form a 3D meander inductor according to one or more exemplary embodiments. The 3D pillar meander inductor top sub-assembly **700** may include a top support structure **702** having a supporting surface **702**S. FIG. **7**B, is a front view from the FIG. **7**A projection **6-6**. Referring to FIG. **7**B, and to the assembly snapshot of FIG. **7**A, after being flipped over for assembly with the FIG. **5**H 3D pillar meander inductor lower sub-assembly **500**-H, the supporting surface **702**S faces the lower substrate **502** supporting surface **502**S.

Referring to FIG. **7**A, the supporting surface **702**S may support pillar top pads such as the first top pad **704-1**, second top pad **704-2**, third top pad **704-3**, fourth top pad **704-4**, fifth top pad **704-5** and sixth top pad **704-6** (collectively "pillar top pads **704**," a label not specifically shown in the figures). The pillar top pads **704** are positioned in alignment with the Cu pillars **522** of the FIG. **5**H 3D pillar meander inductor lower sub-assembly **500**-H. For purposes of example, the 3D pillar meander inductor top sub-assembly **700** is shown configured with the top pad interconnection pattern shown in the 3D meander inductor **150** of FIGS. 3A-3B. Accordingly, a pillar top pad first interconnector **706-1** on the supporting surface **702**S connects first top pad **704-1** to second top pad **704-2**, a pillar top pad second interconnector **706-2** connects third top pad **704-3** to fourth top pad **704-4**, and a pillar top pad third interconnector **706-3** connects fifth top pad **704-5** to sixth top pad **704-6**. For brevity, the pillar top pad first interconnector **706-1**, pillar top pad second interconnector **706-2** and pillar top pad third interconnector **706-3** will be collectively referenced as "pillar top pad interconnectors **706**."

FIG. **8**A is a snapshot diagram of operation **800**A of assembling the 3D pillar meander inductor top sub-assembly **700** of FIGS. 7A-7B onto the 3D pillar meander inductor lower sub-assembly **500**-H of FIG. **5**H. The operation **800**A forms the 3D Cu pillar meander inductor structure **800**B shown in FIG. **8**B.

Referring to FIG. **8**A, an IMC material **802** may be disposed at the pillar tops **522**A, as described in reference to FIG. **5**G. The IMC material **802** may be, for example, solder. However, solder generally has a lower conductivity than Cu. Therefore, in one aspect, direct Cu-to-Cu bonding (not explicitly visible in the figures) of the Cu pillar tops **522**A to the pillar top pads **704**, may be performed. In an aspect, direct Cu-to-Cu bonding may be preferred to increase the conductivity at the top-substrate-to-bottom-substrate-interface and, in turn, increase the Q of the 3D pillar meander inductor that results.

As shown in FIG. **8**A, one or both of the 3D pillar meander inductor top sub-assembly **700** and 3D pillar meander inductor lower sub-assembly **500**-H may be urged together in the "AB" direction. In an aspect, the urging may be configured to maintain an acceptable alignment of the pillar top pads **704** with the Cu pillar tops **522**A. Regarding "acceptable alignment," it will be appreciated by persons of ordinary skill that a tolerance or window of acceptability with respect to the alignment may be application specific. Such persons, though, having view of the present disclosure, can readily determine the tolerance, or window of acceptability by applying basic engineering skills that such persons possess to the described concepts, without undue experimentation. The pillar top pads **704** may then be bonded the Cu pillar tops **522**A in an electrically conductive manner, to obtain the Cu pillar meander inductor structure **800**B shown in FIG. **8**B.

Described examples show the 3D pillar meander inductor lower sub-assembly **500**-H having the entirety of the Cu pillars **522**, and the 3D pillar meander inductor top sub-assembly **700** having only pillar top pads **704** and the pillar top pad interconnectors **706**. In other words, as thus far described, the Cu pillars **522** are formed to their desired height entirely on the areas **514** of the seed layer **512**.

In one alternative embodiment, instead of the Cu pillars **522** being the full height of the completed device's Cu pillars, they may be formed only as a lower section, e.g., one-half, or one-third, of the full height. The upper or top sections of the completed devices' Cu pillars may be formed on the pillar top pads **704** of the 3D pillar meander inductor top sub-assembly **700**. When the 3D pillar meander inductor upper and lower sub-assemblies are aligned, the lower sections of the Cu pillars extend up, and the upper sections of the Cu pillars extend down. On assembly, their distal ends meet and are connected. This can provide 3D pillar meander inductors according to various exemplary embodiments having Cu pillars of a greater height, or at a lower fabrication cost, or both, than can be obtained when formed entirely on, for example, a supporting surface of a lower substrate.

FIG. **9**A shows a projection, from the same view as FIG. **8**A, of one example assembly operation **900**A in assembling a modified 3D pillar meander inductor top sub-assembly **902** onto a modified 3D pillar meander inductor lower sub-assembly **904**. The assembly forms the FIG. **9**B 3D pillar meander inductor **900**B. To avoid possible obfuscation from description of new structures, the modified 3D pillar meander inductor lower sub-assembly **904** will be assumed identical to the 3D pillar meander inductor lower sub-assembly **500**-H in all respects other than its Cu pillars **906**, being formed to a height D**7** less than a desired end height. In other words, the Cu pillars **906** have the same base pad interconnection pattern as the Cu pillars **522**. The modified 3D pillar meander inductor top sub-assembly **902** will be assumed identical in all respects to the FIG. **7**A-**7**B 3D pillar meander inductor top sub-assembly **700** except that downward pointing (relative to the FIG. **9**A drawing sheet) Cu pillars **908** are formed on the pillar top pads **704**, extending downward by a height D**8**. A seed layer (not shown in FIG. **9**A) may also be formed on the pillar top pads **704**. In an aspect, D**7** and D**8** can be equal or unequal.

FIG. **9**B shows a 3D pillar meander inductor **900**B in accordance with various exemplary embodiments, resulting from the FIG. **9**A assembly. The bond regions between the respective distal ends of the Cu pillars **906** and Cu pillars **908** are labeled one flow **1000** in one process of fabricating a 3D pillar inductor according to various exemplary embodiments. Referring to FIG. **10**, example operations can start at **1002** and proceed to **1004** to form, on a lower substrate such as the FIG. **5**A lower substrate **502**, a quantity of base pads (e.g., the FIG. **5**A base pads **504**). The forming at **1004** may include forming base pad interconnectors (e.g., the FIG. **5**A base pad interconnectors **506**). In an aspect, the forming at **1004** can configure the pillar base interconnectors according to the previously described base pad interconnection pattern. Next, at **1006**, the flow **1000** can form a passivation layer over the in-process structure formed at **1004**. The forming at **1006** may be, for example, according to the forming of the passivation layer **508** described in reference to FIG. **5**B. Next, in operations according to the flow **1000**, after forming the passivation layer at **1006**, operations can include, at **1008**, etching or otherwise removing portions of the passivation layer to expose the tops of the base pads. The etching or removing at **1008** can be, for example, according to the etching to expose the top surface areas **510**, previously described in reference to FIG. **5**C.

Continuing to refer to FIG. **10**, after etching or otherwise removing portions of the passivation layer at **1008** to expose the tops of the base pads, operations can include a depositing at **1010** of a seed layer on layer, primarily to cover the exposed top portions of the base pads. The depositing at **1010** can be, for example, as the depositing of the seed layer **512** previously described in reference to FIG. **5**D. Next, after depositing the seed layer at **1010**, operations according to the flow **1000** can, at **1012**, deposit the mold layer. As previously described in reference to FIG. **5**D, the mold layer can be, for example, SiO_2, and can be at a thickness at least the desired length of the pillars (e.g., the FIG. **3**A-**3**B Cu pillars **302**). Next, after depositing the mold layer at **1012**, operations according to the flow **1000** may, at **1014**, etch or otherwise remove portions of the mold layer to form recesses corresponding to the pillars. One example of this operation is the forming of the pillar recesses **518** previously described in reference to FIG. **5**F.

Referring to FIG. **10**, after **1014**, operations according to the flow **1000** may go to **1016** and deposit Cu, or various alternative metals in the recesses etched at **1014**. In an aspect, the depositing at **1016** may be to a depth equal the desired length of the pillars. In another aspect, the depositing at **1016** may be to a depth less than the desired length, to accommodate depositing the IMP on the pillar tips before removing the mold, as previously described in reference to FIG. **5**G. Continuing to refer to FIG. **10**, after depositing the Cu or other metal at **1016** to the desired depth, operations according to the flow **1000** can remove the mold at **1018** to expose the pillars. The resulting structure can be, for example, the base supported pillar and connect structure **500**G previously described in reference to FIG. **5**H.

With continuing reference to FIG. **10**, operations according to the flow **1000** can include, at **1005**, providing, or fabricating, a pillar top connection structure, having a substrate supporting pillar top pads (e.g., the FIG. **3**A-**3**B pillar top pads **310**) and pillar top pad interconnectors (e.g., the FIG. **3**A-**3**B top pad interconnectors **314**). The operations at **1005** can form, for example, the 3D pillar meander inductor top sub-assembly **700** described in reference to FIG. **7**A. Next, operations at **1020** can position the pillar top connection structure over the base supported pillar and pillar connect structure produced at **1018** and then at **1022**, as shown at FIGS. **8**A-**8**B, assemble these to form a 3D pillar inductor in accordance with one or more exemplary embodiments. The flow **1000** can then end at **1024**.

One exemplary alternative embodiment may include a 3D pillar spiral inductor. FIG. **11**A is a front projection of one example 3D pillar spiral inductor **1100** in accordance with various exemplary embodiments. The 3D pillar spiral inductor **1100** can include a lower substrate **1102** having a support surface **1102**S, and an upper or top support surface **1104**S of an upper or top support structure **1104**, spaced above and parallel to the lower substrate **1102**. The 3D pillar spiral inductor **1100** may include plurality of (e.g., six) metal (e.g., Cu) pillars, for example, the Cu pillars **1106-1**, **1106-2** . . . **1106-6** (referenced collectively as "Cu pillars **1106**." It will be understood that the labeling of the Cu pillars **1106-1**, **1106-2** . . . **1106-6** is not in a left-to-right order. In describing example aspects, Cu pillars **1106** may be referred to, individually, as first Cu pillar **1106-1**, second Cu pillar **1106-2**, third Cu pillar **1106-3**, fourth Cu pillar **1106-4**, fifth Cu pillar **1106-5** and sixth Cu pillar **1106-6**.

Each of the Cu pillars **1106** extends from a respective base pillar pad (shown, but not separately labeled) on the support surface **1102**S of the lower substrate **1102** to a respective top pillar pad (shown, but not separately labeled) on the surface **1104**S of the top support structure **1104**. In an aspect, the Cu pillars **1106** may be formed only on the base pillar pads, for an assembly comparable to FIGS. **8**A-**8**B. In another aspect, the Cu pillars **1106** may be formed on both the base pillar pads and the top pillar pads, for an assembly comparable to FIGS. **9**A-**9**B.

For convenience in describing example features, connections to a base pillar pad of a Cu pillar **1106** will be referred to as "a connection to" or "connects to" the "base of Cu pillar **1106**." For like purposes, connections to a top pillar pad of a Cu pillar **1106** will be referred to as "a connection to" or something that "connects to" the "top of Cu pillar **1106**."

FIG. **11**B is a cross-sectional projection from the projection **7-7** facing the support surface **1102**S of the lower substrate **1102**. Referring to FIG. **11**B, the Cu pillars **1106** may be aligned along a linear axis BX, and evenly spaced by a pitch (shown but not separately labeled). The support surface **1102**S may also support a first terminal "TF" connected to the base of the first Cu pillar **1106-1**, and a second terminal "TG" connected to the base of the sixth Cu pillar **1106-6**. An inductor first base segment **1110**, for example, on the support surface **1102**S, connects the base of the third Cu pillar **1106-3** to the base of fifth Cu pillar **1106-5**. The inductor first base segment **1110** may have a major portion (shown but not separately labeled) that may extend parallel BX. The major portion of the inductor first base segment **1110** may be spaced a distance D**11**, in a first direction perpendicular to BX, from an upper (relative to the plane of FIG. **11**B) outer edge of the respective base pads (shown but not separately numbered) of the fourth Cu pillar **1106-4**, fifth Cu pillar **1106-5** and sixth Cu pillar **1106-6**. An inductor second base segment **1112** connects the base of the fourth Cu pillar **1106-4** to the base of the fifth Cu pillar **1106-5**. The inductor second base segment **1112** may likewise have a major portion (shown but not separately labeled) that may also extend parallel BX, but spaced the distance D**11** in a second direction opposite the first direction, from a lower outer edge of the base pad of sixth Cu pillar **1106-6**.

FIG. **11**C is a cross-sectional projection from the FIG. **11**A cut plane **8-8** facing the support surface **1104**S of the top support structure **1104**. Referring to FIG. **11**C, the support surface **1104**S supports an inductor first top segment **1114**, an inductor second top segment **1116**, and an inductor third top segment **1118**. The inductor first top segment **1114** connects the top of Cu pillar **1106-1** to the top of Cu pillar **1106-2**. The inductor first top segment **1114** has a major portion (shown but not separately labeled) extending parallel BX. The major portion of the inductor first top segment **1114** is spaced the above-described distance D**11**, in the first direction, from an upper (relative to the plane of FIG. **11**B) outer edge of the pillar top pads (shown, but not separately labeled) of the fourth Cu pillar **1106-4**, sixth Cu pillar **1106-6** and third Cu pillar **1106-3**. The inductor second top segment **1116** connects the top of the fourth Cu pillar **1106-4** to the top of the third Cu pillar **1106-3**. The inductor second top segment **1116** has a major portion (shown but not separately labeled) extending parallel BX, and spaced the distance D**11** in the second direction from an outer edge of the base pad of the sixth Cu pillar **1106-6**. The inductor third top segment **1118** connects the top of the fifth Cu pillar **1106-5** to the top of the sixth Cu pillar **1106-6**. The inductor third top segment **1118** can extend aligned with BX.

Referring to FIG. **11**A, the above-described structure forms a spiral inductor current path IP having what can be characterized as three rectangular loops. It will be understood that the segments "IPT" and "IPL" of the spiral inductor current IP are drawn with vertically spaced segment lines, but these lines represent multiple, co-planar current segments. For example, an innermost or first loop (shown but not separately labeled) established by the fifth Cu pillar **1106-5** and sixth Cu pillar **1106-6**, together with the inductor third top segment **1118**. A next outer or second loop (shown but not separately labeled), in series with the first loop, is established by the third Cu pillar **1106-3** and fourth Cu pillar **1106-4**, inductor second base segment **1112** and inductor second top segment **1116**. A third or outermost loop is fed by the second loop, and is established by the first Cu pillar **1006-1** and second Cu pillar **1006-2**, inductor first upper segment **1014** and inductor first base segment **1010**.

In an aspect, a sub-section of the FIG. **11**A to **11**C structure may implement a spiral inductor with a reduced quantity (e.g., less than three) loops. For example, the base pad of the second Cu pillar **1106-2** may be assigned as a first terminal, and the base pad of fourth Cu pillar **1106-4** may be assigned as the second terminal. The first Cu pillar **1106-1** and the sixth Cu pillar **1106-6** may be omitted.

Various alternative embodiments of a 3D inductor may employ, in place of the FIG. **3**A-**3**B metal (e.g., Cu) pillars **302**, solder ball inductor segments configured and arranged to function, for example, as the arms of a 3D meander inductor.

FIG. **12** shows one alternative 3D meander inductor lower sub-assembly **1200** having, in place of the metal (e.g., Cu) pillars **302** of the FIG. **3**A-**3**B pillar meander inductor **350**, solder ball inductor segments. In the FIG. **12** example, the solder ball inductor segments include a first solder ball **1202-1**, a second solder ball **1202-2**, a third solder ball **1202-3**, a fourth solder ball **1204-4**, a fifth solder ball **1202-5** and a sixth solder ball **1202-6** (collectively "solder ball inductor segments **1202**," a label not appearing on the figures). To avoid unnecessary added description it will be assumed that, except where specifically stated, or where made clear from the context to be otherwise, the alternative 3D meander inductor lower sub-assembly **1200** is structured identical to the FIG. **5**H example 3D Cu pillar meander inductor lower sub-assembly **500**-H. To reduce duplicative labeling, like structures are not numbered. The solder ball inductor segments **1202** may each be formed on a wetting surface, of which one representative example is numbered **1204**.

FIGS. **13**A-**13**B show a snapshot sequence of example operations in an assembly process assembling a 3D meander inductor top sub-assembly **1302** onto the FIG. **12** 3D meander inductor lower sub-assembly **1200**. To avoid unnecessary added description it will be assumed that, except where specifically stated, or made clear from the context to be otherwise, the 3D meander inductor top sub-assembly **1302** is identical to the FIG. **7**A-**7**B example 3D pillar meander inductor top sub-assembly **700**, and like structure is not numbered. In an aspect, the 3D meander inductor top sub-assembly **1302** may include wetting surfaces (not explicitly shown in FIGS. **13**A-**13**B) disposed on the FIG. **7**A pillar top pads **704**.

Referring to FIG. **13**B the result of the assembly shown by the FIG. **13**A snapshot provides a 3D meander inductor **1350**, providing a meander current path LP. As shown, the meander current path LP is within a plane that is normal to the plane (shown, but not separately labeled) that supports the solder ball inductor segments **1202**.

Exemplary embodiments and aspects have been described hereinabove in reference to examples having Cu pillars arranged along a linear axis, e.g., the FIG. **4**A axis AX. 3D inductors according to one or more further embodiments may include 3D Cu pillar inductors having two-dimensional, or X-Y arrangements of conducting, e.g., Cu pillars. In an aspect, one example 3D Cu pillar inductor having two-dimensional, e.g., X-Y arrangements of Cu pillars in accordance with various exemplary embodiments may provide N-turn Cu pillar coil inductors.

In one aspect, an N-turn Cu pillar coil inductor may be provided, comprising two adjacent rows or columns of N Cu pillars, the two rows or columns extending, for example in the X direction. The spacing between the adjacent rows or columns may be in the Y direction. A winding axis may be defined as extending parallel to, and between the two adjacent rows or columns. Along either of the adjacent rows or columns, the base of each of the N Cu pillars may be linked, for example, by a pillar base cross-connector that crosses, in the Y direction, under the winding axis to the base of a corresponding opposing Cu pillar in the other row or column. In an aspect, a resulting structure may be a concatenation of N partial windings. Each of the N particle windings may be formed of a pair of opposing Cu pillars straddling the winding axis and linked, at their respective pillar tops, by a pillar base interconnector. In an aspect, the pillar base interconnector may pass under, and be bifurcated by the winding axis. In a further aspect, the concatenation of N partial windings may be formed into a concatenation of N full windings by N−1 adjacent winding links that cross diagonally over the winding axis between particular pillar tops of the adjacent rows or columns.

In an aspect, a fabrication of an N-turn Cu pillar coil inductor according to various exemplary embodiments may include fabricating an N-turn Cu pillar coil inductor lower sub-assembly having, on a lower substrate, the described rows or columns of Cu pillars, linked by pillar cross-connectors to form a concatenation of N partial windings. In a further aspect, an N-turn Cu pillar coil inductor upper or top sub-assembly may be fabricated, having N−1 adjacent winding links. The N-turn Cu pillar coil inductor top sub-assembly may be arranged such that when assembled with the N-turn Cu pillar coil inductor lower sub-assembly, the N−1 adjacent winding links cross diagonally over the winding axis, and connect Cu pillar tops in a pattern forming a concatenation of N full windings.

FIG. **14**A is a plan view of a lower sub-assembly **1400** of a 3-turn Cu pillar coil inductor (not shown in its entirety in FIGS. **14**A-**14**B) in accordance with one or more exemplary embodiments, viewed from a direction normal to a support surface **1402**S of, for example, a lower substrate **1402**. FIG. **14**B is a front view, from the FIG. **14**A projection **9-9**. For brevity, the phrase "lower sub-assembly **1400** of a 3-turn Cu pillar coil inductor in accordance with one or more exemplary embodiments" will be recited in the abbreviated form "pillar coil inductor lower sub-assembly" **1400**. As described later in greater detail, the pillar coil inductor lower sub-assembly **1400** may be configured for subsequent assembly with a pillar coil inductor upper or top sub-assembly (not shown in FIGS. **14**A-**14**B) to form a 3-turn Cu pillar coil inductor according to one or more exemplary embodiments.

Referring to FIG. **14**A, the lower substrate **1402** may be a portion of a larger lower substrate (not necessarily entirely visible in the figures). The support surface **1402**S may support the row of Cu pillars **1404-1**, **1404-2**, **1404-3**, **1404-4** (collectively "Cu pillars" **1404**) and, on the opposite side of the given winding axis "CX," the row of Cu pillars **1406-1**, **1406-2**, **1406-3**, **1406-4** (collectively "Cu pillars" **1406**). As will be appreciated by persons of ordinary skill in the art after reading this disclosure, in the example shown by FIGS. **14**A-**14**B, Cu pillar **1406-4** may be omitted. The row of Cu pillars **1404** may be along row line "TX," and the row of Cu pillars **1406** may be along row line "VX." It will be understood that the row lines TX and VX are shown as linear only for purposes of example, as practices according to various exemplary embodiments may include a pillar coil inductor comprising a non-linear X-Y arrangement of its Cu pillars.

Referring to FIG. **14**B, the Cu pillars **1404** may be equally spaced from one another by a pitch **P5** along the TX row line. In an alternative embodiment, the Cu pillars **1404** may be unequally spaced. In an aspect, the Cu pillars **1406** may be arranged along row line VX in a manner identical to, or approximately the same as the arrangement of the Cu pillars **1404** along row line TX. The pitch from row line TX to row line VX is P**6**. It will be understood that the pitch P**5** and P**6** can be significantly smaller than the pitch P**1** and P**2** of the FIG. **1** related art TGV inductors.

Referring to FIG. **14**B, the winding axis CX is shown elevated a height D**14** above the support surface **1402**S. In one aspect, the height D**14** may be approximately one-half the height D**15** of the Cu pillars **1404** and **1406**. In an aspect, though, a pillar coil inductor top sub-assembly may have top sections (not visible in FIGS. **14**A-**14**B) of Cu pillars, such that the height of the Cu columns (not necessarily shown in FIGS. **14**A-**14**B) of the final pillar coil inductor into which the pillar coil inductor lower sub-assembly **1400** is assembled is greater than D**15**. In such aspects, D**14** may be greater than one-half of D**15**.

Referring to FIGS. **14**A-**14**B, the Cu pillars **1404** and Cu pillars **1406** are shown as disposed on respective base pads (shown but not separately numbered.) To avoid obfuscation by description of structural detail, connections to the respective pillar pad of a particular Cu pillar **1404** or **1406** will be referred to as a "connection to the base of" or "connects to the base of" the particular Cu pillar **1404** or **1406**.

Referring to FIG. **14**A, the support surface **1402**S may support a pillar base cross-connector **1408-1** that connects at one end (shown but not separately numbered) to the base of Cu pillar **1404-1**, crosses under the winding axis WX, and connects at its other end to the base of Cu pillar **1406-1**. In a similar manner, pillar base cross-connector **1408-2** connects at one end to the base of Cu pillar **1404-2**, crosses under the winding axis CX, and connects to the base of Cu pillar **1406-2**. The combination of the Cu pillars **1404-1**, **1406-1**, **1404-2**, and pillar base cross-connector **1408-1** may be referred to as a "first partial turn" of the 3-turn pillar coil inductor lower sub-assembly **1400**.

In like manner, a base cross-connector **1408-3** connects at one end to the base of Cu pillar **1404-3**, crosses under the winding axis CX, and connects to the base of Cu pillar **1406-3**. The combination of the pillar base cross-connector **1408-2**, and the Cu pillars **1406-2** and **1404-2** may be referred to as a "second partial turn" of the 3-turn pillar coil inductor lower sub-assembly **1400**. Continuing, the pillar base cross-connector **1408-3** connects at one end to the base of Cu pillar **1404-3**, crosses under the winding axis CX, and connects to the base of Cu pillar **1406-3**. The combination of the pillar base cross-connector **1408-3**, and Cu pillar **1406-3** and Cu pillar **1404-4** may be referred to as a "third partial turn" of the pillar coil inductor lower sub-assembly **1400**. For purposes of describing example operations, a first terminal lead **1410** is shown connected to the base of pillar **1404-1**, and a second terminal lead **1412** is shown connected to the base of pillar **1404-4**.

FIG. **15** is a plan view of one example Cu pillar coil inductor upper or top sub-assembly **1500** configured for assembly with the pillar coil inductor lower sub-assembly **1400**, to form a 3-turn pillar coil inductor (visible in its entirety in FIG. **15**) according to one or more exemplary embodiments. FIG. **16**A shows, as sub-assembly **1601**-B, a front view of the Cu coil inductor top sub-assembly **1500**, from the FIG. **15** projection plane **10-10**, after being flipped over for assembly with the pillar coil inductor lower sub-assembly **1400**.

Referring to FIG. **15**, the supporting surface **1502**S supports two rows of four pillar top pads, namely, the row of pillar top pads **1504-1** . . . **1504-4**, and the row of pillar top pads **1506-1** . . . **1506-4**. In an aspect, pillar top pad **1506-4** may be omitted. The rows of pillar top pads **1504-1** . . . **1504-4** and **1506-1** . . . **1506-4** can be positioned to align with the tops of pillars **1404-1** . . . **1404-4**, and the tops of pillars **1406-1** . . . **1406-4**, respectively, when Cu coil inductor top sub-assembly **1500** is aligned above the pillar coil inductor lower sub-assembly **1400**.

A top first adjacent turn link **1508-1** connects at one end (shown but not separately numbered) to pillar **1506-1** and extends diagonally to pillar top pad **1504-2**. A top second adjacent turn link **1508-2** connects at one end (shown but not separately numbered) to pillar **1506-2** and extends diagonally to pillar top pad **1504-3**. In like manner, a top third adjacent turn link **1508-3** connects at one end (shown but not separately numbered) to pillar top pad **1506-3** and extends diagonally to pillar top pad **1504-4**.

FIG. **16**A, as previously described, shows a snapshot of one example operation in assembling the above-described pillar coil inductor top sub-assembly **1500** onto the pillar coil inductor lower sub-assembly **1400** modified by an IMG **1602** formed on the tops of the Cu pillars **1404-1** . . . **1404-4**, and Cu pillars **1406-1** . . . **1406-4** (not explicitly visible in FIG. **16**A). One or both of the sub-assemblies **1500** and **1400** may be urged along the "AB" axis, to move together with proper alignment. Referring to FIG. **16**B, a bonding of the pillar top pads **1504-1** . . . **1504-4** to the tops of pillars **1404-1** . . . **1404-4**, and pillar top pads **1506-1** . . . **1506-4** to the tops of pillars **1406-1** . . . **1405-4** forms a pillar coil inductor **1600**B according to one or more exemplary embodiments

FIG. **17** is a top view of the 3-turn pillar coil inductor **1600**B from the FIG. **16**B projection **11-11**, showing in hidden lines the pillar cross connectors **1408-1**, **1408-2**, and **1408-3** crossing under the winding axis CX and the pillar adjacent turn links **1508-1**, **1508-2**, and **1508-3** passing, diagonally, over the winding axis CX.

FIG. **18** illustrates an exemplary communication system **1800** in which one or more embodiments of the disclosure, e.g., as described in reference to any one or more of FIGS. **3**A-**3**B, **4**A-**4**B, **5**A-**5**H, **8**A-**8**B, **9**A-**9**B, **10**, **11**A-**11**C, **12**, and **13**A-**13**B, may be advantageously employed. For purposes of illustration, FIG. **18** shows three remote units **1820**, **1830**, and **1850** and two base stations **1840**. It will be recognized that conventional wireless communication systems may have many more remote units and base stations. The remote units **1820**, **1830**, and **1850** include integrated circuit or other semiconductor devices **1825**, **1835** and **1855** having one or more pillar inductors in accordance with one or more of the disclosed exemplary embodiments, e.g., as described in reference to any one or more of FIGS. **3**A-**3**B, **4**A-**4**B, **5**A-**5**H, **8**A-**8**B, **9**A-**9**B, **10**, **11**A-**11**C, **12**, and **13**A-**13**B. FIG. **18** shows forward link signals **1880** from the base stations **1840** and the remote units **1820**, **1830**, and **1850** and reverse link signals **1890** from the remote units **1820**, **1830**, and **1850** to the base stations **1840**.

In FIG. **18**, the remote unit **1820** is shown as a mobile telephone, the remote unit **1830** is shown as a portable computer, and the remote unit **1850** is shown as a fixed location remote unit in a wireless local loop system. These are only examples, both in terms of quantity and type. For example, the remote units **1820**, **1830** and **1850** may be one of, or any combination of a mobile phone, hand-held personal communication system (PCS) unit, portable data unit such as a personal data assistant (PDA), navigation device (such as GPS enabled devices), set top box, music player, video player, entertainment unit, fixed location data unit such as meter reading equipment, or any other device that stores or retrieves data or computer instructions, or any combination thereof. Although FIG. **18** illustrates remote units according to the teachings of the disclosure, the disclosure is not limited to these exemplary illustrated units. Embodiments of the disclosure may be suitably employed in any device having active integrated circuitry including memory and on-chip circuitry for test and characterization.

The foregoing disclosed devices and functionalities, e.g., as described in reference to any one or more of FIGS. **3**A-**3**B, **4**A-**4**B, **5**A-**5**H, **8**A-**8**B, **9**A-**9**B, **10**, **11**A-**11**C, **12**, and **13**A-**13**B, may be designed and configured into computer files (e.g. RTL, GDSII, GERBER, etc.) stored on computer readable media. Some or all such files may be provided to fabrication handlers who fabricate devices based on such files. Resulting products include semiconductor wafers that are then cut into semiconductor die and packaged into a semiconductor chip. The chips are then employed in devices described above.

Those of skill in the art will appreciate that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Further, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

The methods, sequences and/or algorithms described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor.

While the foregoing disclosure shows illustrative embodiments of the invention, it should be noted that various changes and modifications could be made herein without departing from the scope of the invention as defined by the appended claims. The functions, steps and/or actions of the method claims in accordance with the embodiments of the invention described herein need not be performed in any particular order. Furthermore, although elements of the invention may be described or claimed in the singular, the plural is contemplated unless limitation to the singular is explicitly stated.

What is claimed is:

1. A three-dimensional (3D) inductor, comprising:

a first row of conducting members and a second row of conducting members, each extending a height from a corresponding base pad on a given base pad support surface up to a corresponding top pad on a given top pad support surface facing the given base pad support surface, wherein the first row of conducting members and the second row of conducting members are arranged parallel to, and on opposite sides of, a given winding axis that is parallel to and between the given base pad support surface and the given top pad support surface;

a first base cross-connector extending from a base pad of a first conducting member in the first row of conducting members, under the given winding axis, to a base pad of a first conducting member in the second row of conducting members, wherein the two base pads are formed of a seed layer on and in contact with the first base crossconnector; and each of the two base pads has a side aligned with a side of the corresponding one of the two first conducting members formed thereon;

a first adjacent turn link, extending from a top pad of the first conducting member in the second row of conducting members, over the given winding axis, to a top pad of a second conducting member in the first row of conducting members, adjacent to the first conducting member in the first row of conducting members;

a second base cross-connector extending from a base pad of the second conducting member in the first row of conducting members, under the given winding axis, to a base pad of a second conducting member in the second row of conducting members, adjacent to the first conducting member in the second row of conducting members; and

a second adjacent turn link, extending from a top pad of the second conducting member in the second row of conducting members, over the given winding axis, to the top pad of a third conducting member in the first row of conducting members, adjacent to the second conducting member in the first row of conducting members.

2. The 3D inductor of claim **1**, wherein the first conducting member in the first row of conducting members is a metal first pillar, and the second conducting member in the first row of conducting members is a metal second pillar.

3. The 3D inductor of claim **1**, wherein the first conducting member in the first row of conducting members, the top pad of the first conducting member in the first row of conducting members, the first adjacent turn link, the top pad of the first conducting member in the second row of conducting members, and the first conducting member in the second row of conducting members establish a meander current path from the base pad of the first conducting member in the first row of conducting members to the base pad of the first conducting member in the second row of conducting members.

4. The 3D inductor of claim **3**, wherein a height and a pitch of the first conducting member in the first row of conducting members and a height and a pitch of the first conducting member in the second row of conducting members are configured wherein the meander current path establishes an inductor approximating a meander inductor having two arms with an arm length corresponding to the height of the first conducting member in the first row of conducting members and an arm spacing corresponding to the pitch of the first conducting member in the first row of conducting members, having the base pad of the first conducting member in the first row of conducting members as a first terminal and the base pad of the first conducting member in the second row of conducting members as a second terminal.

5. The 3D inductor of claim **4**, wherein the first conducting member in the first row of conducting members is a metal first pillar and the first conducting member in the second row of conducting members is a metal second pillar.

6. The 3D inductor of claim **5**, wherein the metal first pillar is a first copper (Cu) pillar and the metal second pillar is a second Cu pillar.

7. The 3D inductor of claim **4**, wherein the first conducting member in the first row of conducting members is a first solder ball, having a base that is solder bonded to the base pad of the first conducting member in the first row of conducting members, and a top that is solder bonded to the top pad of the first conducting member in the first row of conducting members, and the first conducting member in the second row of conducting members is a second solder ball, having a base that is solder bonded to the base pad of the first conducting member in the second row of conducting members, and a top that is solder bonded to the top pad of the first conducting member in the second row of conducting members.

8. The 3D inductor of claim **7**, further comprising:

a lower substrate having a top surface including the given base pad support surface; and

a top support structure having a bottom surface including the given top pad support surface.

9. The 3D inductor of claim **8**, wherein a top support structure comprises an integrated circuit (IC) chip supported in a flip-chip configuration by the lower substrate, the IC chip has a bottom surface that is the given top pad support surface.

* * * * *